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S&L MANIPULATED PIPEWORK

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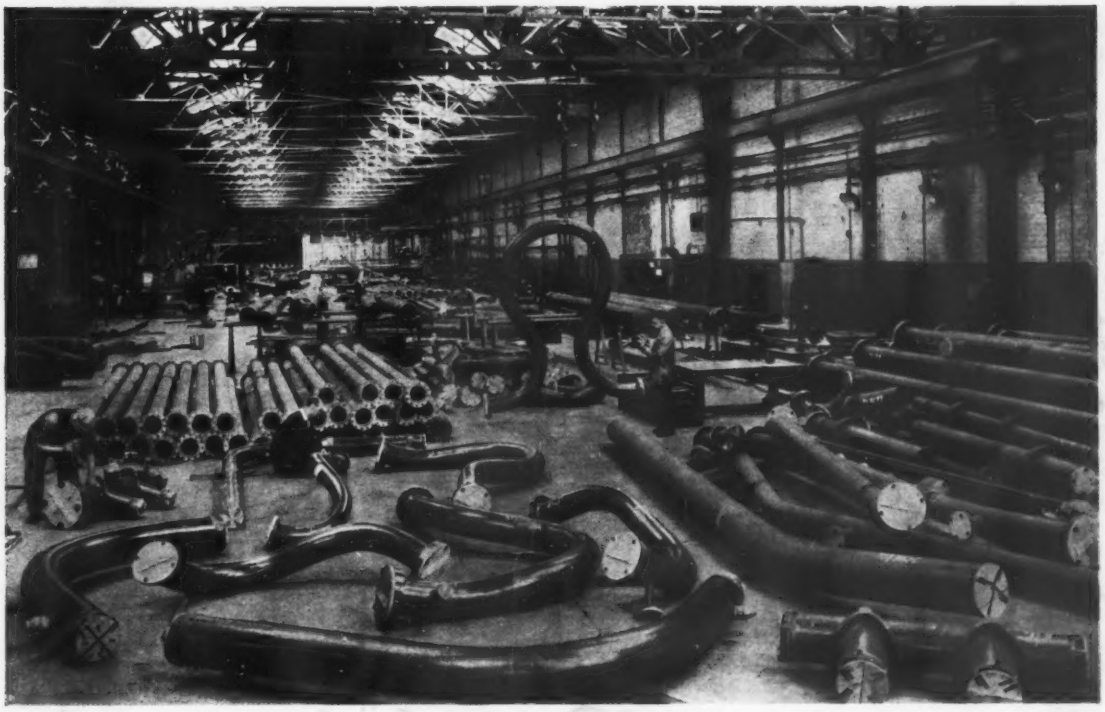

ABOVE: *Manipulated high pressure pipework in the assembly, inspection and despatch bays at Stewarts and Lloyds' Tollcross Works, Glasgow.*

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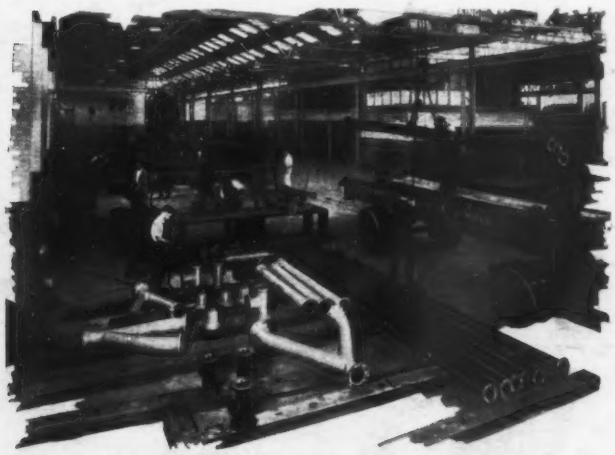
BELOW: *New fabricating shop at Pudding Mill Lane, Marshgate Lane, Bow, E.15.*



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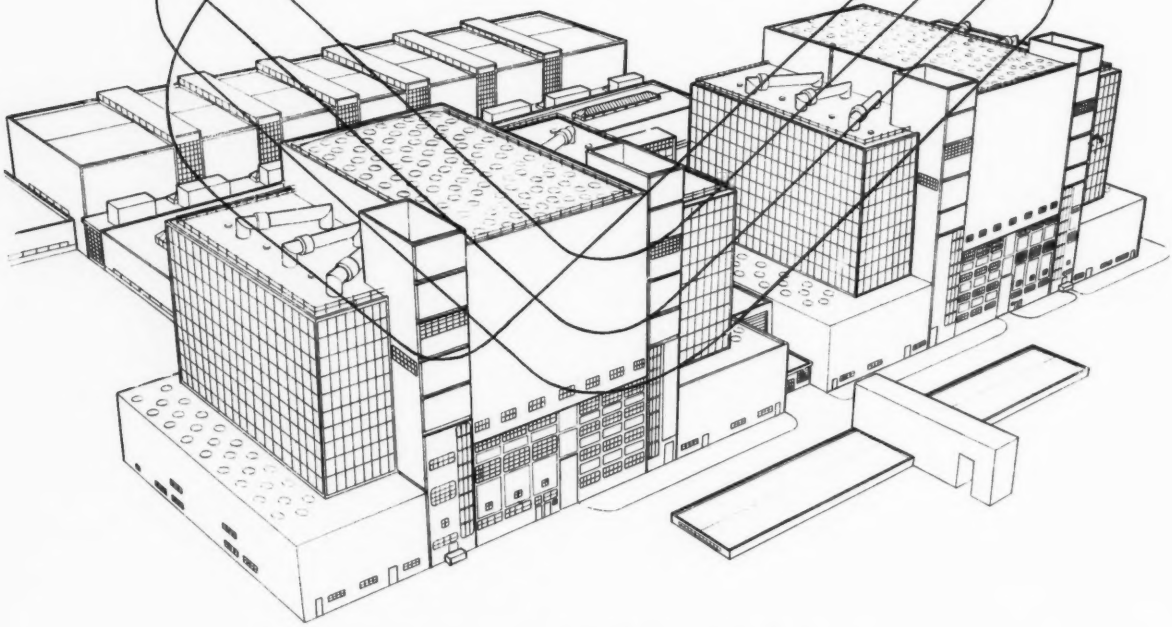

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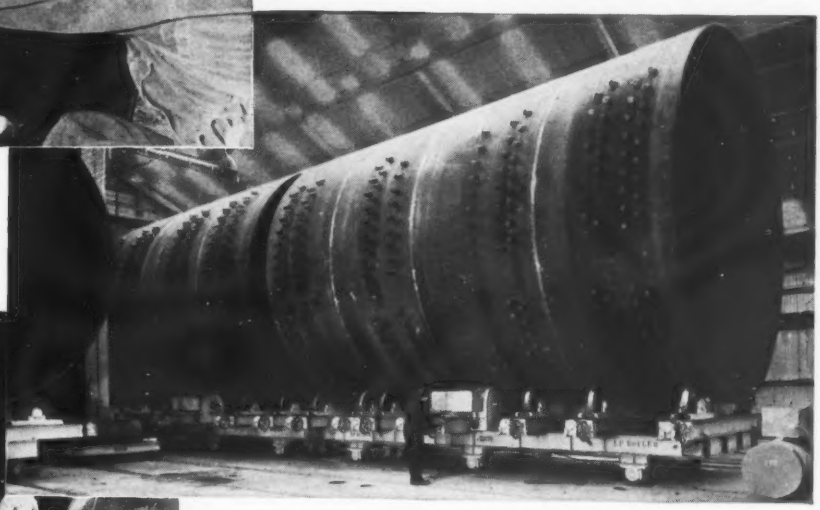

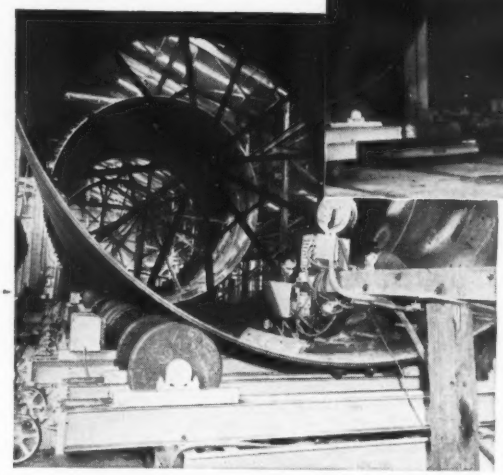

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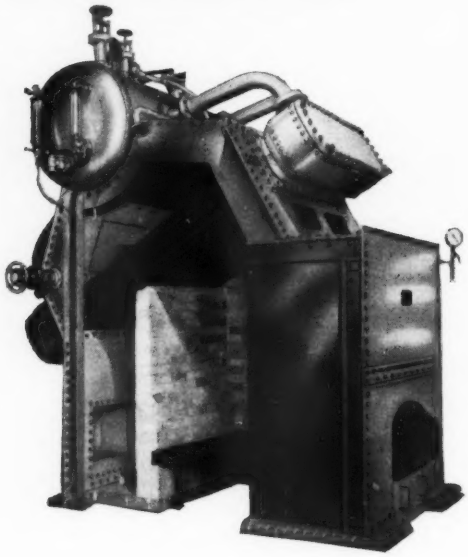

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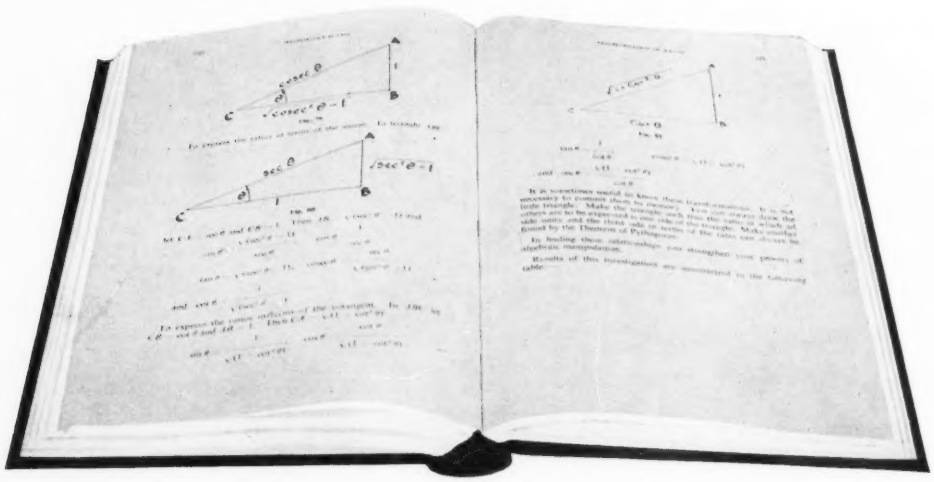

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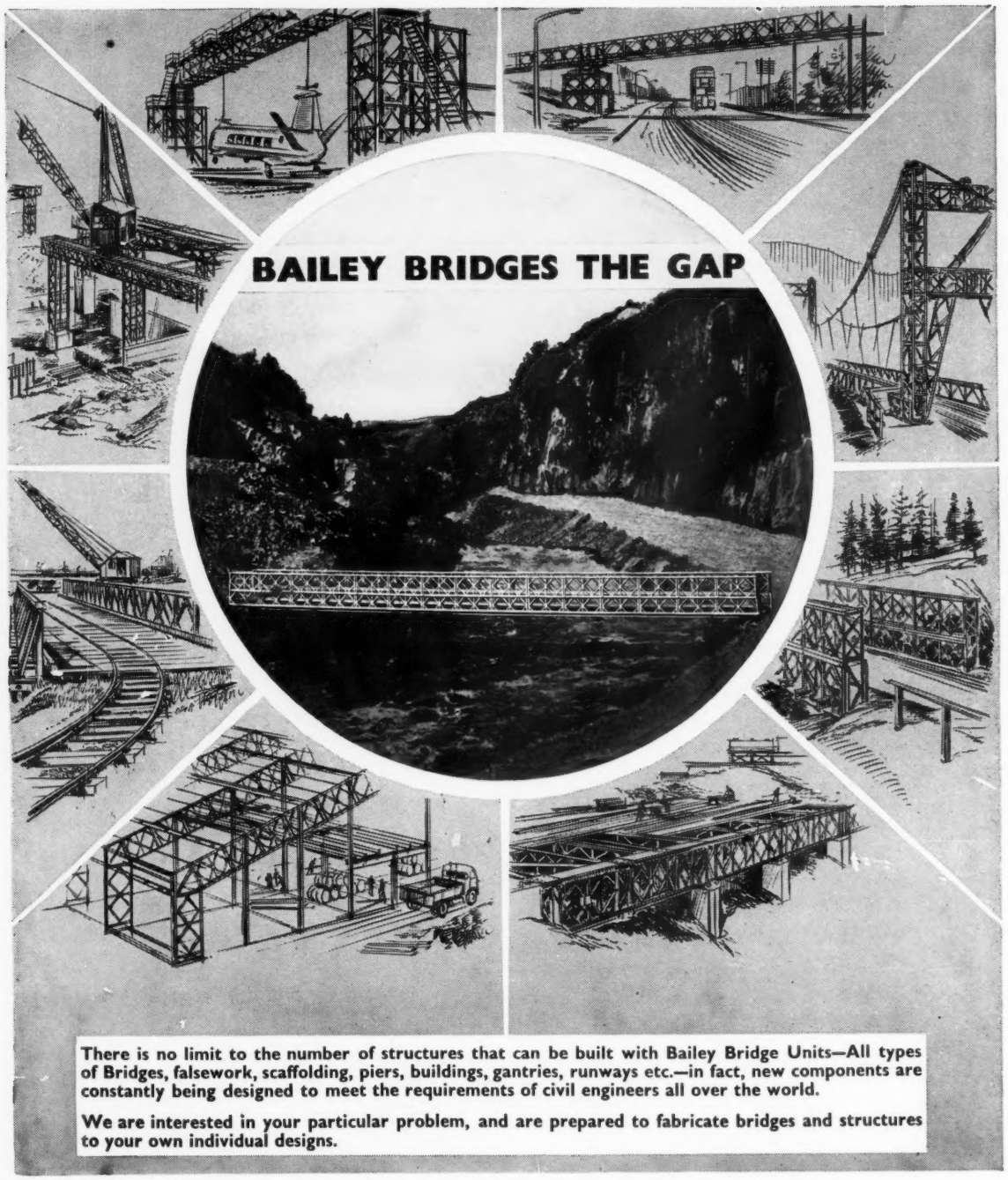
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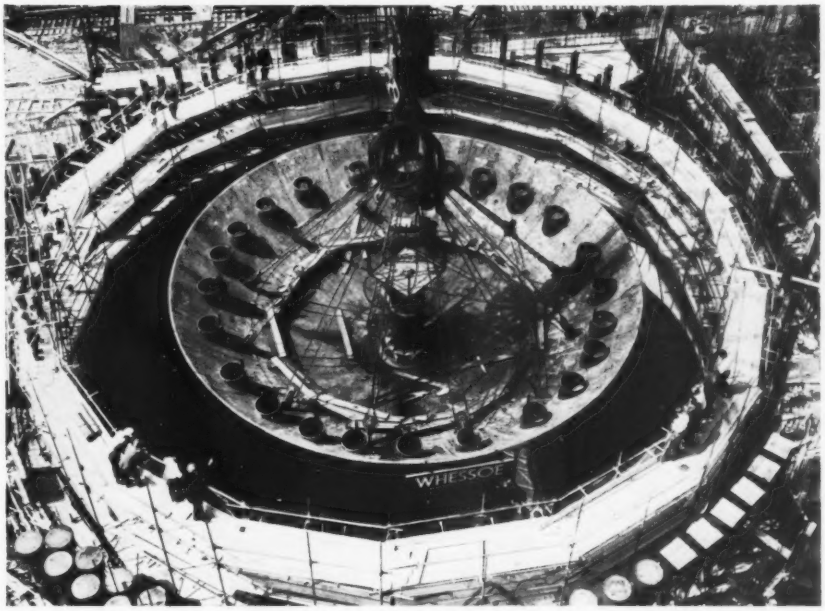

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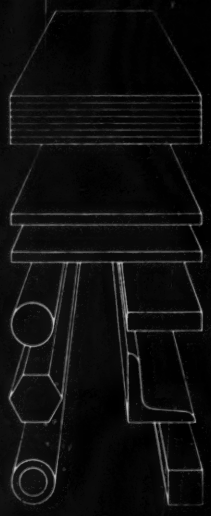

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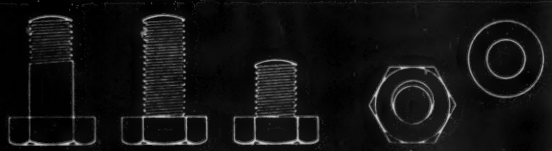

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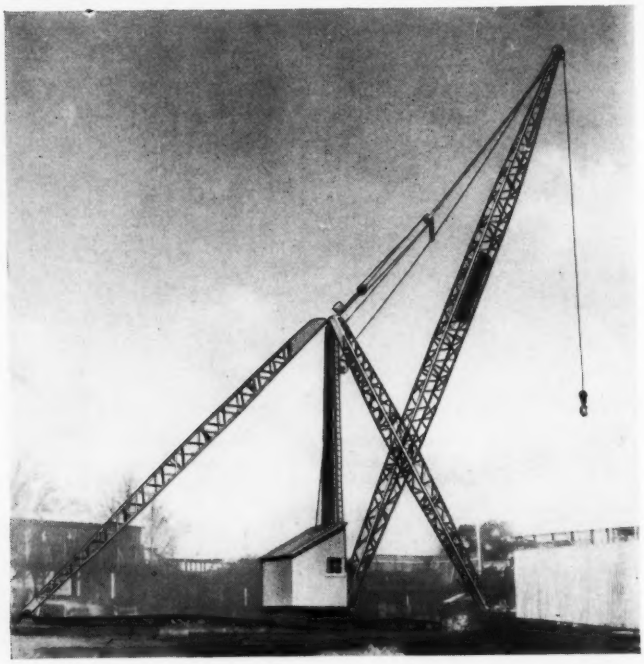

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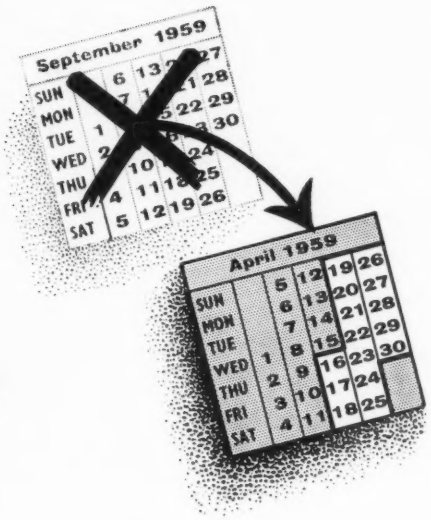

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NUCLEAR ENERGY ENGINEER

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JANUARY, 1959

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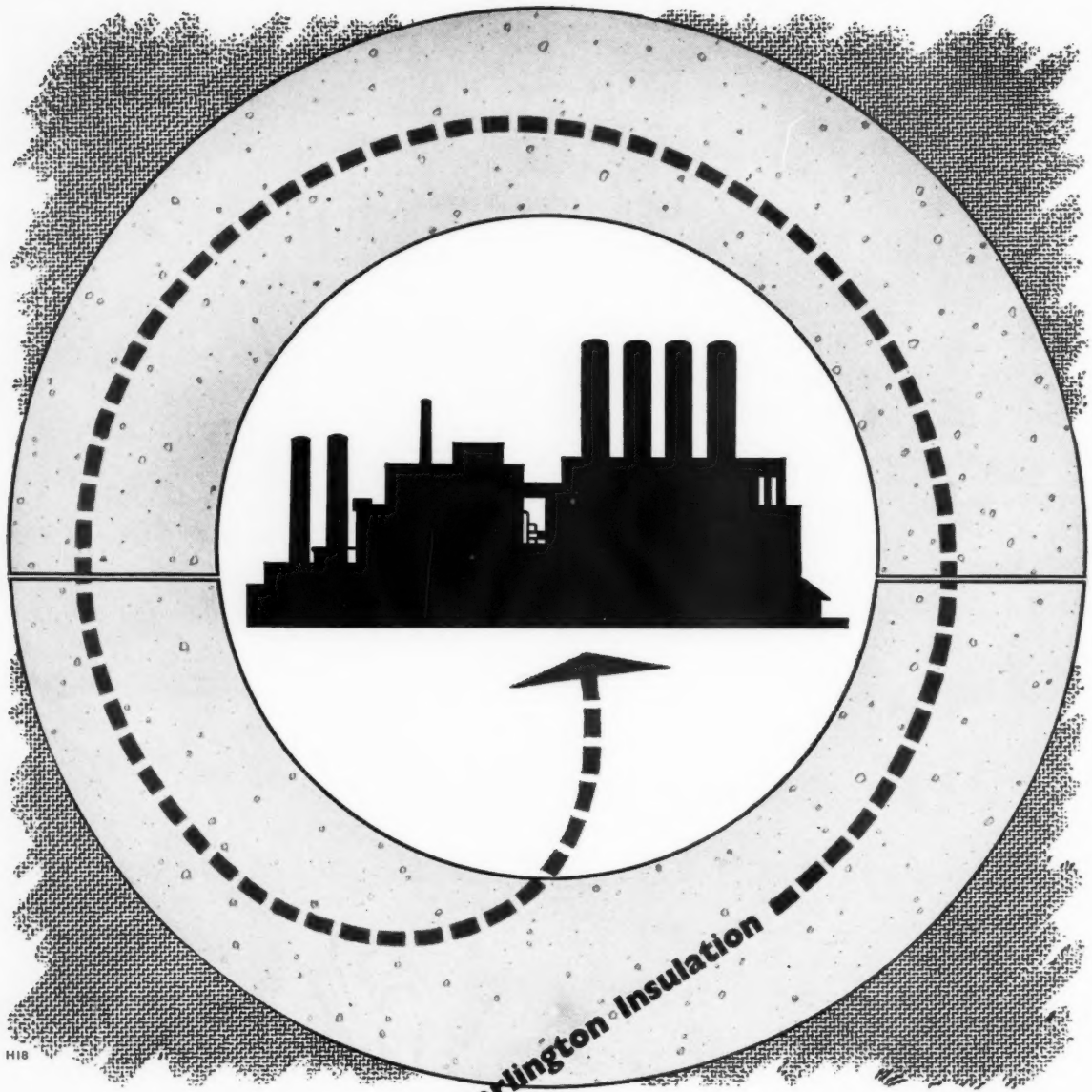

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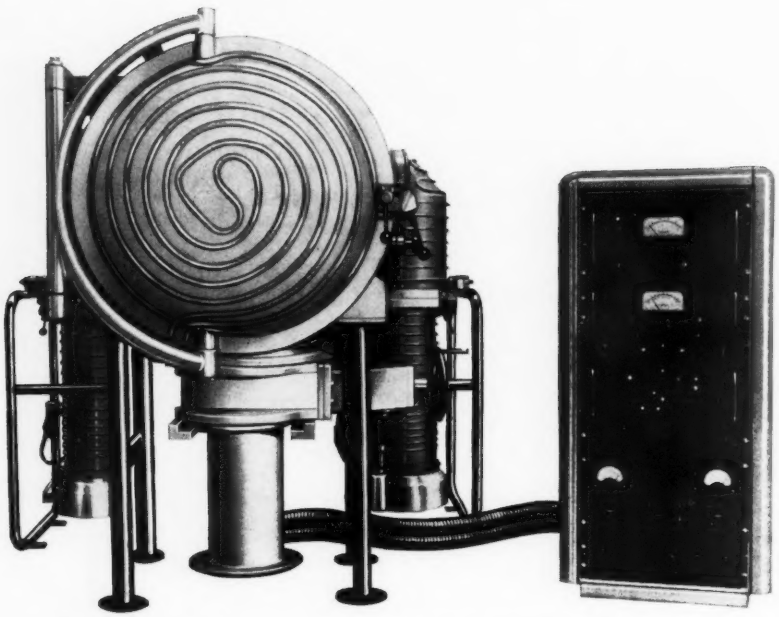

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A technician studying irradiated fuels at the Hanford nuclear research laboratories, Richland, Washington, U.S.A.

HANDLING RADIOACTIVE WASTES

Experiences at Hanford

HIGH level radioactive wastes from irradiated fuels may be characterized generally as being either acid or alkaline, concentrated, aqueous, hazardous to living organisms because of their intense radioactivity and capable of spontaneous and prolonged boiling through the absorption of their own radiant energy. Such characteristics present problems in the sorting of radioactive wastes and it is how to overcome these that Hanford Atomics Products Operation, of Richland, Washington, devote some of their research.

At present the most economical and reliable means of storage are found to be earth-covered metal and concrete tanks. These, because they are buried underground, have to be built to resist high external earth pressures, and, in certain cases, ground water pressures, in addition, the property of the wastes to heat themselves and boil irregularly results in pressure changes and thermal variations which require special design and structural considerations.

50m. Gallons

Wastes stored in ordinary steel tanks have to be kept alkaline. Wastes in acid condition have to be stored in stainless steel, the extra costs involved being justified in certain operations. Generally in operations involving millions of gallons of wastes they are kept in concentrated alkaline form in ordinary steel. At Hanford alone it is reported that about 50m. gal. are stored in such facilities.

The tanks are in groups of multiple units, each with a capacity from ½m. to 1m. gal, an internal diameter of about 75 ft and a height from 20-40 ft. Monitoring equipment for measuring liquid heights, sludge levels, and temperatures is installed and there are facilities for ensuring adequate heat removal and for eliminating or minimizing the surge boiling characteristics of the wastes.

With the development of the solvent extraction process for the recovery of uranium and plutonium it was found the heat generation phenomenon reached levels which required the provision of cooling facilities more elaborate than those used previously.

During the operation of the obsolete precipitation process for plutonium production, self heating of the wastes was expected. Simple finned-tube air-cooled condensers were adequate for condensing the water vapour from the small amount of vent gases. These wastes, which were of a large volume because no effort was made to concentrate them for minimum storage costs, did not attain boiling temperatures.

Boiling Overcome

Solvent extraction process wastes, however, because of intensive efforts to minimize salt content and to reduce their volume, rapidly attain boiling conditions and are expected to continue to boil for many years. In order to eliminate uncontrolled boiling, air lift circulators, or agitators, have been installed in all the tanks.

Though storage in tanks is at present the most suitable method available it is realized that it has certain limitations, including finite capacity, uncertain durability, vulnerability to accidents and significant costs, which make it necessary to find improved methods. Investigations are in fact, being made into the conversion of liquid wastes into inert solids by calcination (*see* NUCLEAR ENERGY ENGINEER, December, 1958), the solids then being stored in caverns, abandoned mines, etc.

Better Tank Storage

Investigations, however, are also still being made into methods of improving tank storage. The safe storage period of liquids, for instance might be extended by removing the long-lived radioisotope Sr-90. The waste would then exist at a lower temperature and, presumably, under less severe corrosion conditions.

Details for this article were extracted from a paper presented at the 2nd International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1958.

RADIOACTIVE WASTE GASES

Extraction by Silver Reactor Method

SCIENTISTS of Hanford Atomic Products Operation, Richland, Washington, have found the silver reactor method the best for removing radioactive iodine gas from the Hanford processing plant. The basis of operation is the use of a silver bearing, reacting bed at a high temperature. Iodine reacts chemically with the silver and is retained in the bed.

The silver reactor consists of a tower which can be packed with any suitable silver bearing-bed. The diameter of the tower should be sized to give a superficial velocity of about 1 ft/sec. Where space is available a length-to-diameter ratio of about four is suggested; high collection efficiencies can be obtained with considerably smaller length-diameter ratios, but the useful life of the unit will be shortened.

Nitrate is Used

The most economical means of obtaining a highly developed silver surface area for the reacting bed is through the use of Berl saddles which have been coated with silver nitrate, and this method had been the most widely used. For the preparation of this type of packing, unglazed ceramic Berl saddles are immersed in an 18-20 molal silver nitrate solution for 1 min, allowed to drain, and then baked at 220°F. for 4hr. After baking, the packing is cooled to room temperature and then charged into the reactor tower. The control temperature for a reactor using this type of packing is 380°F.

Intricate Reactions

The chemistry of the silver reactor is quite complex. The entering gases can contain NO_2, O_2, H_2O, N_2, and $ICl+I_2$ (or $ICl+Cl_2$ with some NOCl depending on whether iodine or chlorine is in excess). For the removal of iodine, the following individual reactions can be considered:

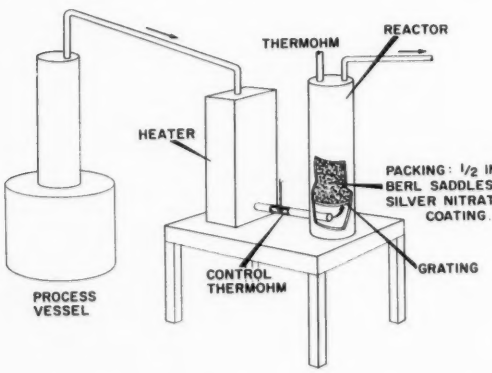
$$AgNO_3+1/2\ I_2 \rightleftarrows AgI+1/2\ O_2+NO_2 \quad . \quad . \quad . \quad (1)$$

$$AgNO_3+1/2\ I_2+O_2 \rightleftarrows AgIO_3+NO_2 \quad . \quad . \quad . \quad . \quad (2)$$

$$AgIO_3 \rightleftarrows AgI+3/2\ O_2 \quad . \quad . \quad (3)$$

Thermodynamic considerations would predict, and this has been confirmed by a subsequent analysis of a portion of a reactor bed following its service life, that AgI is the stable product under the reactor operating conditions.

The situation is further complicated by the fact that in some of the reactor applications the gas stream can contain NH_3 and H_2 (at these times the oxides of nitrogen and probably the halogens are absent). Under these conditions, NH_3 combines with $AgNO_3$ to form an addition compound, $AgNO_3.xNH_3$ which in turn decomposes partially to yield $AgNO_3$, Ag metal, $AgNO_3.xNH_3$ and a trace of AgN_3. The thermodynamics of iodine removal by this method has been rather thoroughly considered elsewhere[1].



Simplified drawing showing arrangement of silver reactor for extracting waste radioactive iodine gas

Two of the more important factors should be emphasized. The equilibrium pressure of iodine increases with the square of the NO_2 pressure and to a lesser extent with the O_2 pressure as shown by the relationship:

$$P\,I_2=\frac{(P\,NO_2)^2\,(P\,O_2)}{K^2} \quad . \quad . \quad (4)$$

The equilibrium pressure of iodine is strongly dependent upon the reaction temperature and high collection efficiencies are favoured by a high operating temperature. With the use of a silver nitrate coating, however, the control temperature is limited to approximately 380°F. This is necessary since care must be exercised not to exceed the melting point of the silver nitrate and thus cause a flowing of the coating from the packing surface.

Collection Efficiency

The optimum performance which has been obtained with a plant-scale reactor using a silver nitrate coated packing is a removal efficiency in the order of 99.99 per cent. Monitoring data indicate that the reactor operated in this manner for approximately one year before the collection efficiency began to decrease.

It must be emphasized, however, that this represents *optimum* rather than general performance. As a result of the many variables which can affect the process, the over-all removal efficiency of "new" reactors has been in the range of 99.7 to 99.9 per cent. and the over-all efficiency of "regenerated" reactors has been in the order of 99.5 per cent.

Restoration

Experience has shown that when the collection efficiency of a reactor begins to fall it can be "regenerated" and a large measure of its removal efficiency restored. This is accomplished by fitting a spray head at the top of the reactor packing. The

unit is allowed to cool to 150°F. and the packing is sprayed with 0.04 cu.ft of five molal silver nitrate solution/cu.ft of ceramic packing. After the spraying, the reactor bed is heated to 220°F. and allowed to bake for four hours; again the reactor is cooled, sprayed in the same manner, and then baked at 230°F. for six hours. Following the two spraying and baking periods, the unit is returned to service.

Several Times Over

Experience has also shown that a reactor can be regenerated in this manner some seven to ten times. After this number of regenerations, the flow resistance across the unit becomes excessive. This increased flow resistance is caused by a plugging of the bottom packing support grid with a heavy coating of silver nitrate crystals and other silver salts[2]. This deposit grows in size with succeeding regenerations because the liquid reaching the bottom grid is saturated and does not dissolve in any previous deposit. After seven to ten regenerations, the crystal mass on the supporting grid becomes almost continuous.

The operating performance of the silver reactors has been very satisfactory. The nature of the process, however, requires a considerably greater attention to operating variables than is the case with the deep-bed fibrous filters. The following factors are particularly important in the operation of the silver reactors.

Operating Factors

1. If the reactors are permitted to operate below 375°F., the collection efficiency is lowered; if the temperature falls below the condensation point of nitric acid vapours (230°F.), practically no iodine removal occurs. If a reactor using silver nitrate is permitted to operate above 413°F., the life of the unit will be seriously affected due to the melting and flowing of the silver nitrate coating from the column packing.

2. Either stable iodine or chlorine can saturate a reactor or displace radioactive iodine which has been collected. For this reason, care should be exercised that the chemicals used in the process do not contain appreciable amounts of chlorine or iodine.

There has been one instance of a fast exothermic reaction in a silver reactor. This followed an attempt to unplug a silver reactor which had been regenerated approximately ten times. An ammonium hydroxide flush was used to unplug the reactor. The flush was effective in decreasing the flow resistance of the unit. The reactor was then given a thorough water flush, dried, sprayed with silver nitrate solution, and returned to service. Shortly afterwards a rapid exothermic reaction occurred.

Laboratory information has shown that this reaction resulted from the decomposition of an unstable product which had been formed by a reaction with ammonia. The particular compound has not been identified; nor has the source of the ammonia been established conclusively.

References

[1]BURGER, L. L., "Thermodynamics of Iodine Removal With The Silver Reactor," General Electric Co., Hanford Atomic Products Operation, Document No. HW-38311 (July 1st, 1955).

[2]AMOS, L. C., "Regeneration of Silver Reactors," General Electric Co., Hanford Atomic Products Operation, Document No. HW-41053 (December 27th, 1955).

Details for this article were extracted from a paper on "Treatment of Radioactive Waste Gases" by A. G. Blasewitz and W. C. Schmidt presented at the 2nd International C.P.U.A.E.

RED—but no herrings . . .

by The Editor

TEMPTED as we were to indulge in fashionable end-of-year retrospect, we have resisted the urge to inflict on our readers the back-slapping eulogies of the season. We prefer, instead, the forward look, offering the fulfilment of promises which but a short time ago were surrounded by the aurora of a dream world.

Was it only yesterday that the world applauded the birth of Calder Hall, or is this another of time's tricks, aided by the rapidity of subsequent developments? If the quickness of the pace has deceived the memory, how observant must we be to keep abreast of the expected events of 1959?

In Britain, we must be alert in readiness for the completion of Berkeley and Bradwell power stations... Dounreay will become critical during the year... Chapelcross will be approaching completion... and the entire nuclear fraternity will be waiting to learn which of the consortia has won the Trawsfyndd 500 MW contract.

On the Continent, the Marcoule reactor is due to reach "full steam" conditions in 1959, in addition to which the French have two research reactors scheduled for completion during the year and Germany has one. The Swiss, too, are well in the race with their reactor at Wurenlingen.

Perhaps the most anxiously-awaited developments will be those within the Soviet Union. The shroud of mystery having been systematically lifted since Geneva, the prospects of Soviet advances in the nuclear field are less reliant on speculation. Sir John Cockcroft would be the first to agree that he saw only that which he was allowed to see during his recent visit to Russia, but he was sufficiently impressed to lay great store on the developments which must inevitably take place in the Soviet Union during the next two years. The significance of the Russians' willingness to reveal some of their achievements is their obvious capacity for development. True, the door has not been opened wide enough to reveal what stands behind it, but this does not mean that details arranged in view are red herrings. Soviet scientists have covered sufficient ground to dispense with the secrecy which indicated their inferior hand.

If one is to draw conclusions from Sir John Cockcroft's demeanour on his return, speed will be of prime importance in the year ahead.

30 MW HEAVY WATER REACTOR

Swiss Underground Project

P. de Haller and A. F. Fritzsche, of Sulzer Bros. Ltd., presented at the Second International Conference on the Peaceful Uses of Atomic Energy a paper on a project for an underground nuclear heating and power plant. Brief details of the reactor are given in this article.

INVESTIGATIONS into the use of nuclear energy for meeting future power needs in Switzerland have been progressing for over three years. One outcome has been the preparation by a group of firms of a project for the installation of a 30 MW (thermal) station at Zurich, the operation of which would be a step towards a larger plant.

The proposed plant would be utilized either for the production of electricity or in combination with the existing district heating scheme of the Swiss Federal Institute of Technology.

Because of the plant's location, it is suggested that the best site for it would be an underground cavern. Particular attention has, in fact, been paid in the entire conception of the plant to questions of operational safety.

The reactor is heavy-water moderated and cooled and utilizes predominantly natural uranium as fuel. It is designed on the pressure-tube principle, in which coolant and moderator are separated by a pressure carrying wall.

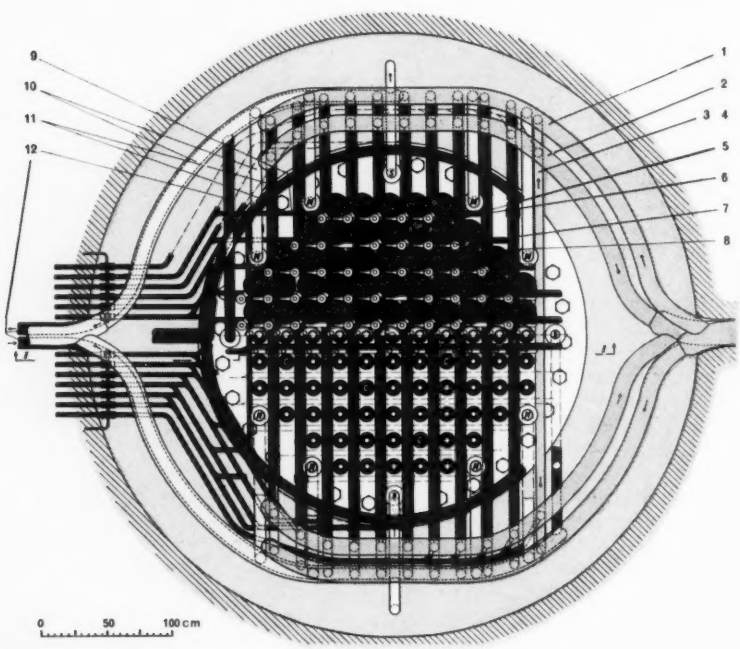
The heavy water coolant is pressurized to about 60 atmospheres, entering the reactor core at about 190°C. and leaving for the steam generators at a temperature of about 220°C. The moderator is kept under nominally atmospheric pressure and at a temperature of approximately 50°C. by circulating it through a separate coolant system. The heat removed from the moderator, about 8 per cent. of the total heat production, is not utilized in any way. The moderator is contained in a cylindrical aluminium tank, surrounded at the sides and below by a graphite reflector. A total quantity of 18 tons of heavy water will be required, of which 13 tons are in the moderator system.

Partly Enriched

The bulk of the 5 tons of fuel are in the form of natural uranium, but a small number of the fuel elements consist of uranium enriched to 1 per cent. in the isotope U-235, which are arranged in an outer annular zone of the core. A partial enrichment has been chosen for this small reactor merely in order to increase the reactivity and thus to reduce the investment cost of the prototype.

A general layout of the reactor can be seen from the vertical section and the plan shown on these pages.

A total of 88 fuel elements arranged in a regular pattern, pass through the top shield and are immersed in the heavy-water moderator. This is contained in a thin-walled aluminium tank with a flat bottom, which rests on a supporting structure. The tank



Horizontal section through reactor core

Key:—1 Main coolant distributor pipe; 2 Main coolant collector pipe; 3 Main coolant distributor manifold; 4 Main coolant collector manifold; 5 Main coolant inlet pipe; 6 Main coolant outlet pipe; 7 Slide valve; 8 Tube mounting for fuel element; 9 Fuel element monitoring system; 10 Collector system for moderator cooling; 11 Moderator bleed-off system; 12 Piping system for shield cooling; C Control rod; M Moderator outlet; S Shield coolant connection

itself is open at the top, sealing the moderator space from the surrounding reflector against the lower surface of the top shield by means of a flange flexibly connected to a supporting ring. The moderator enters the tank through two inlets in the bottom and is drawn off through eight outlets at the circumference of the top shield.

Graphite Reflector

Below and at the sides the moderator tank is surrounded by a reflector of reactor graphite, built up on the bottom shield in the form of blocks and cooled by circulating CO_2.

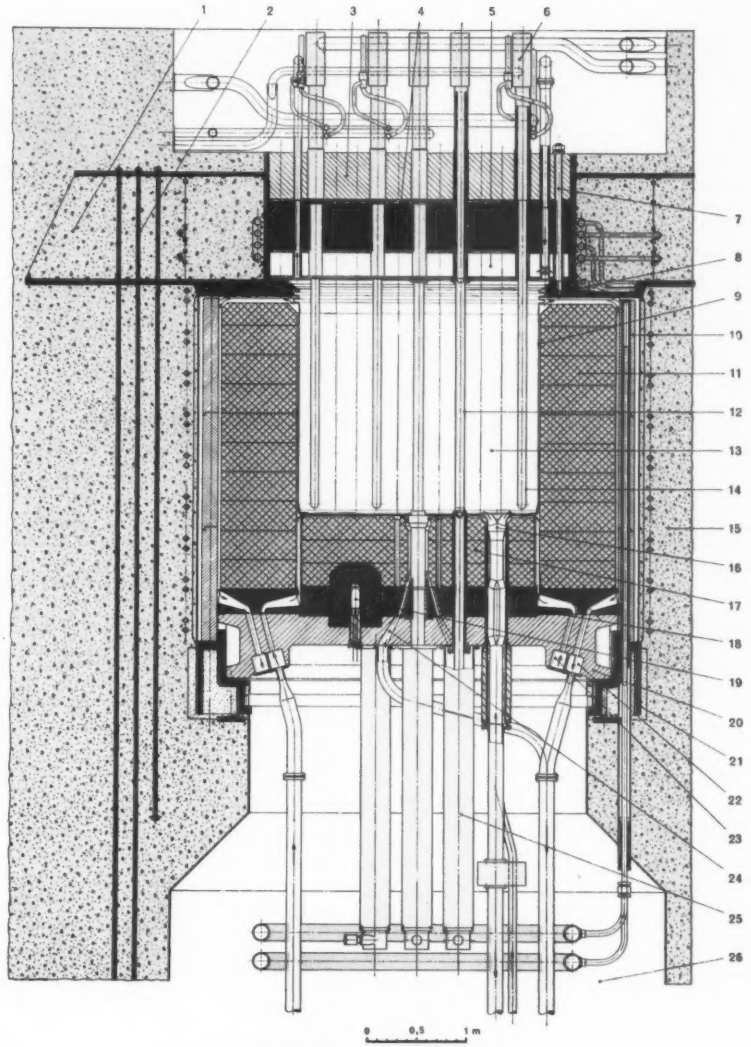
The thermal shielding below the core consists of cast-iron baseplates and a cast-steel plate which carries the weight of the moderator and reflector and rests on a foundation ring. The core is shielded at the sides by cast-iron rings placed on top of each other. These shields are cooled by pipe coils embedded in lead.

The shielding above the reactor consists of a hollow steel structure plated with stainless steel and filled with iron spheres and water, and a cast-steel cover, also plated, arranged above it. In order to seal the moderator space off from the outside, these covers make seals with each other and with the supporting ring and are held together by elastic-shank bolts which take up the forces acting on the covers in the event of an accident to the core, transmitting them through the supporting structure to the prestressed tie-bolts and the concrete. The remaining shielding of the subsidiary rooms at the sides is ensured by a thick concrete wall which is separated from the cast rings and cooled by pipe coils.

Above and Below

The rooms above and below the reactor are only accessible after shutting-down, and the shielding for them has been dimensioned accordingly.

The top covers have 88 apertures for inserting the fuel elements, and a further 9 apertures, also in lattice positions, to take the control rods in their uppermost position. The drive mechanisms for these rods are arranged below the reactor and move the absorber portions down into the core by means of extension tubes. The control rods are immersed directly in the moderator for cooling.



Vertical section through the reactor

Key:—1 Supporting structure; 2 Pre-stressed tie-rods; 3 Steel cover plate; 4 Steel shield structure; 5 Water shield; 6 Fuel element mounting; 7 Upper shield bolts; 8 Supporting ring; 9 Moderator tank; 10 Radial thermal shield; 11 Radial reflector; 12 Control rod; 13 Moderator; 14 Fuel element; 15 Radial biological shield; 16 Moderator inlet; 17 Lower reflector; 18 Lower shield plate; 19 Neutron counter; 20 Baseplate; 21 Foundation ring; 22 Coolant outlet, radial reflector; 23 Reflector coolant inlet; 24 Coolant outlet, lower reflector; 25 Control rod drive; 26 Expansion space

The apertures in the shielding are closed by fixed plugs.

A total of 11 electronic counters for neutron flux measurements are also built into the bottom shield. Some of these are arranged in groups and provided with lead shielding towards the core. The system of control envisaged will not be described in any greater detail here.

As a result of the fuel elements being designed as individual pressure units, the supply and return lines for the heavy-water coolant require an extensive distribution network.

Both the pipe network distributing the coolant to the fuel elements and that collecting the return flow consist of a set of pipes running through the alleys between lattice positions at two levels and connecting up to distributor and collector bends round the circumference of the lattice. Connection of the individual fuel elements to these manifolds is effected through the valves by means of pipe bends which are sufficiently

flexible to take up any thermal expansion.

In order to monitor each fuel element during operation, individual measurements of the activity and temperature of the heavy water leaving the element are envisaged, possibly supplemented by quantitative flow measurements. For this purpose samples are taken from each element and led, suitably combined, through a pipe system to the measuring point. Further collector and distributor pipe networks are required to collect the moderator leaving the core and lead it to the heat exchanger and to circulate the light-water coolant through the upper shield.

The Fuel Elements

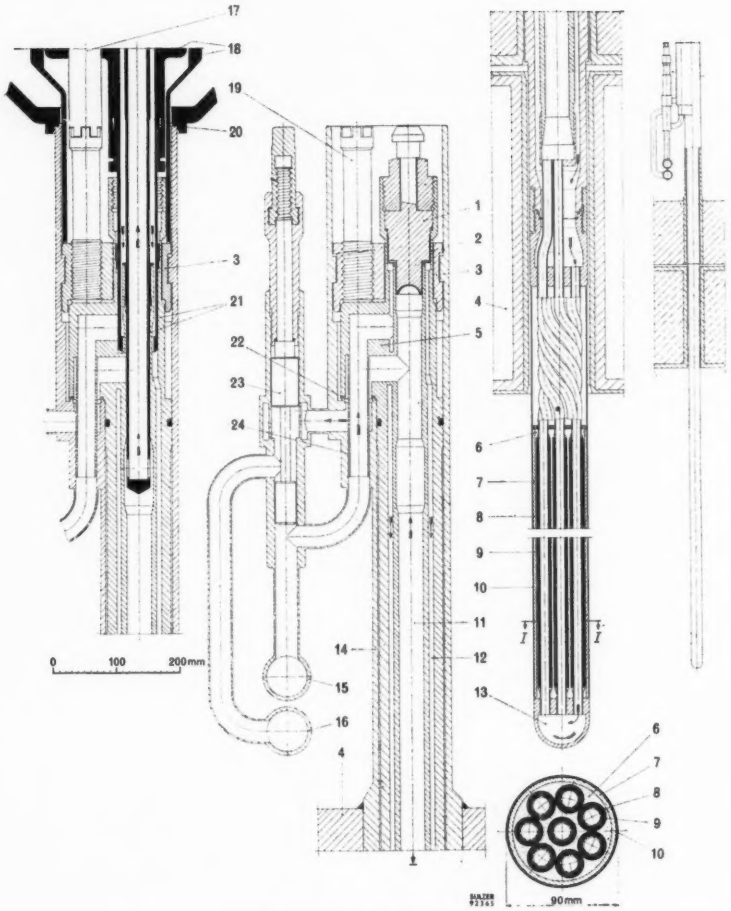
The fuel element is divided into a lower fuel portion containing the uranium and an upper portion which connects up to the cooling ducts in the reactor.

The fuel portion consists of a group of eight tubes, as can be seen in cross-section *I-I*. The components which take the full operating pressure are tubes of zirconium alloy, around which the uranium is also arranged in tubular form. The uranium is thus cooled only from the inside; it is metallically bonded to the zirconium tube and does not have to withstand any pressure itself. Eight of these tube elements form a group and are housed in an outer shell tube, which is separated from the hot uranium surfaces by insulation.

The spaces between the tube elements and the insulation tube are filled with powdered graphite of reactor grade. The obvious advantage of these internally cooled fuel elements is their marked economy of absorbent structural material, as the element which takes the pressure of the coolant is a tube of small diameter.

Coolant Flow

In the design shown on this page, the individual tube elements are fixed in plates at their upper and lower ends, and are connected to the concentric flow and return ducts in such a way that the coolant flows down through four elements, turns round in the bottom header and flows back upwards through the other four elements.



Pressure tube fuel element

Key:—1 Plug; 2 Sealing membrane; 3 Closure unit; 4 Upper reactor shield; 5 Fuel element headpiece; 6 Graphite powder filling; 7 Insulation tube; 8 Uranium tube; 9 Zirconium pressure tube; 10 Outer casing tube; 11 Coolant return duct; 12 Coolant supply duct; 13 Coolant header; 14 Tube mounting for fuel element; 15 Distributor manifold pipe; 16 Collector manifold pipe; 17 Box spanner for main tightening spindle; 18 Tool head of changing machine; 19 Main tightening spindle; 20 Sealed connection to changing machine; 21 Cooling pipes from changing machine; 22 Main seal; 23 Double slide valve; 24 Coolant connecting pipe

The connecting head of the fuel element consists of a headpiece which contains the cooling ducts and effects the connection with the coolant distribution system of the reactor at the main seal, a fixing unit which secures the fuel element in its position inside the reactor, and a plug which enables the element to be connected to the cooling system of the changing gear when it is to be removed.

When the reactor is in operation the coolant passes from the distribution pipe through a valve and connecting pipe into the headpiece, and is there led into the annular flow duct. The heated coolant leaves the fuel portion through the return duct, is diverted in the headpiece, passes through the main seal and flows through the valve into the collector manifold. The concentric arrangement of the coolant connections makes it possible to manage with a single seal to the outside. This seal is tightened up by means of a spindle lying on the same axis.

Why D_2O was Chosen

With natural uranium as fuel the choice of moderator is confined to heavy water, beryllium and graphite. The selection of heavy water for this reactor was made for various reasons.

Heavy water is the medium with the best moderating properties of all

feasible materials, combining excellent moderation with exceptionally low neutron absorption characteristics. As a result of this, the critical size is smaller with a D_2O moderator than with beryllium or graphite. The extremely large size of graphite moderated reactors leads to excessively large material investments, so that this reactor type is not very attractive for a country which has to import all its raw materials.

Less Difficult

Though the production of heavy water requires isotope separation facilities, these are incomparably less extensive and costly than those needed for the separation of enriched fuel, and the raw material is available in unlimited quantities. Plants of large capacity are in operation in a number of countries, while pilot plants operating on various principles are also available in Switzerland. On the other hand the production of beryllium and its technology are in a too early stage of development to base an immediate reactor programme on its use.

The radiation damage effects in graphite and beryllium are less well understood and may lead to appreciable difficulties, whereas a great deal of experience has shown that the effects on heavy water may be coped with satisfactorily.

The critical size of a D_2O-moderated reactor increases rapidly with increasing temperature, so that a very substantial saving is possible by keeping the moderator cool. To achieve this, a thermal insulation is required between the hot coolant and fuel zone and the moderator. With a little care in the selection of the insulating material the increased neutron absorption introduced in this way will only slightly reduce the beneficial effect.

The choice of coolants for a heavy water natural uranium reactor is quite extensive and ranges from various gases through water and organics to liquid metals. Heavy water and gases are distinguished by exceptionally low neutron absorption characteristics. This property is not only relevant with respect to the critical size but also has an important bearing on the safety of the reactor, owing to the fact that a partial loss of strongly absorbing coolant from the core leads to an increase in reactivity, thereby violating the general principle of failure to safety.

Could be Complicated

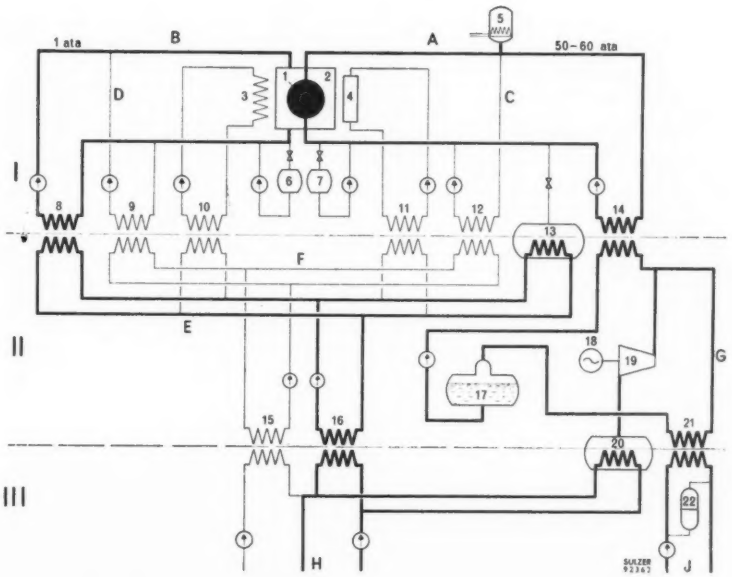
Any coolant differing from the moderator (in this case D_2O) requires an absolutely certain separation between these two media which takes account also of possible defects. From a design point of view this can only be achieved by means of double separation barriers.

The determining factor in the selection of heavy water not only as moderator but also as coolant was the very broad basis of industrial experience with pressurized water accumulated over a long period in the construction of conventional steam power plants. Compared to this experience, the technologies of organic media and liquid metals are still in a very early stage of development, so that their application in the design of a reactor which should be realized within reasonable time and with the scale of effort presently available in Switzerland seemed not to be justified.

Safety Consideration

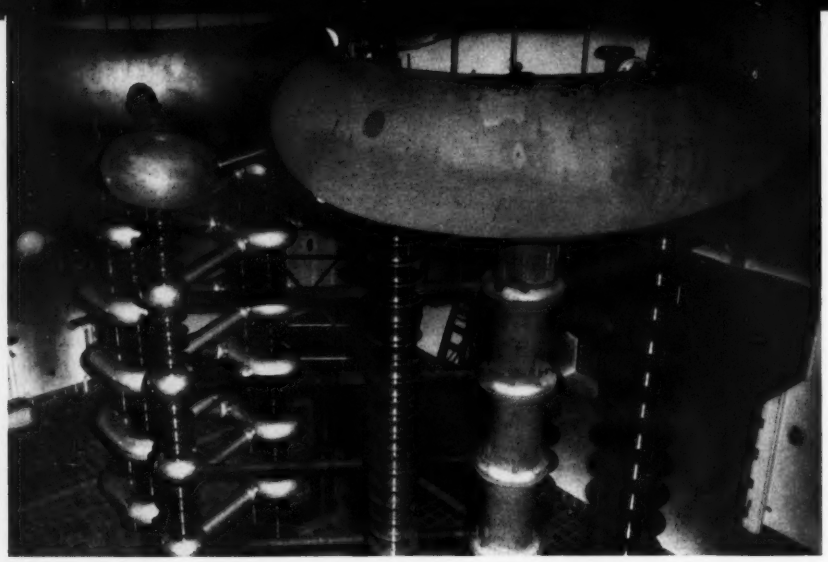
The general principle of the main coolant systems is shown in the simplified flow sheet on this page. In this diagram special attention has been paid to a clear representation of the separation between the various systems which has been provided for safety reasons. The upper part of the flow sheet shows the reactor circuits, i.e., those circuits which include the various parts of the reactor and may in one way or another form a source of radioactive contamination. The lower part of the diagram indicates the external circuits, which are in direct contact with the surroundings and should, therefore, not under any circumstances contain any radioactivity. Between these two groups, closed intermediate circuits have been arranged which will be free of contamination during normal reactor operation and in which it will be easy to distinguish any leaks from the reactor circuits before there is any danger of contaminating the external ones. It may be mentioned in passing that this radical separation of reactor and external circuits is also in the interests of the conservation of heavy water.

(*Continued on page 34*)



Flow sheet showing cooling system

Key:—1 Reactor; 2 Moderator; 3 Shield, 4 Reflector; 5 Pressurizer; 6 D_2O storage tank, moderator system; 7 D_2O storage tank, main coolant system; 8 Main cooler, moderator system; 9 Auxiliary cooler, moderator system; 10 Cooler for shield cooling; 11 Cooler for reflector cooling; 12 Auxiliary cooler, main coolant system; 13 D_2O condenser; 14 Steam generator; 15 Cooler for auxiliary intermediate system; 16 Cooler for main intermediate system; 17 Feed water tank; 18 Electrical generator; 19 Steam turbine; 20 H_2O condenser; 21 Steam transformer; 22 Steam accumulator



A view of the 1m. volt Cockcroft-Walton machine at Liverpool University's nuclear physics laboratory

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UNIVERSITIES distinguish themselves by their research. Their reputations as seats of learning are made not on their production of graduates but on the contributions they make to the advancement of knowledge.

Among British universities that can claim distinction in this way in the nuclear field is Liverpool, which, with its 156 in. synchrocyclotron, has one of the most advanced and flourishing nuclear physics laboratories in Western Europe.

The laboratory owes its present position principally through the work of Sir James Chadwick, FRS, who was Lyon Jones Professor of Physics there from 1935 until 1949. He went to Liverpool from the Cavendish Laboratory, Cambridge, shortly after his discovery of the neutron, and took with him a distinction not experienced by the university since the days of the late Sir Oliver Lodge.

Research Into Fission

Sir James was one of the few British protagonists of the feasibility of the atom bomb and under his direction a considerable amount of work was carried out at Liverpool during the days of the war on fission problems. In 1944 he headed a contingent of British scientists who went to America to help in the development of the bomb at Los Alamos.

After the war, Sir James initiated the programme leading to the construction of Liverpool's 156 in. synchrocyclotron and of the new laboratory buildings. Before the synchrocyclotron was finally built he returned to Cambridge to become master of Gonville and Caius College and his work at Liverpool was taken over by Professor H. W. B. Skinner, FRS, known earlier for his work on soft X-ray spectroscopy and radar, who had also been on the atom bomb team in the U.S.A. and was subsequently Chief Physicist at Harwell.

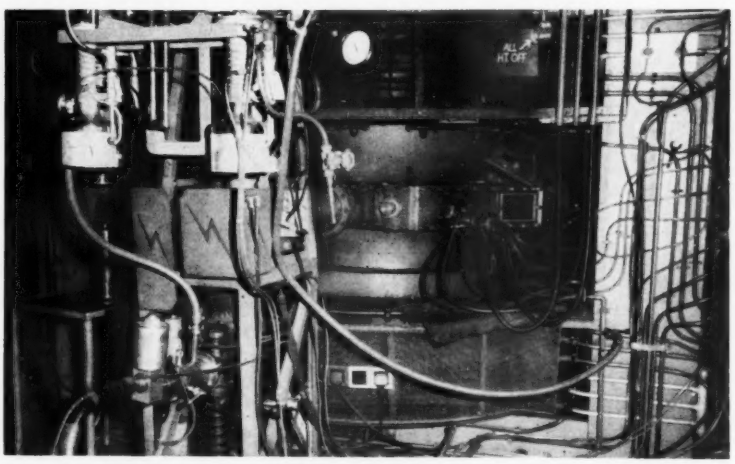
Next to R.C. Cathedral

The new laboratory, which is adjacent to the Roman Catholic cathedral site, was completed in 1950. In addition to the synchrocyclotron, it houses a 37 in. cyclotron and a 1m. volt H.T. Cockcroft-Walton machine. The small cyclotron has a maximum energy of 9 MeV and, put into operation in 1938, was used extensively by Sir James.

Other equipment includes a β-ray spectrograph, cloud chambers, nuclear emulsion equipment for particle detection, ionization chambers and other basic nuclear physics research apparatus.

A 10 in. liquid hydrogen bubble chamber for use with the synchrocyclotron is nearing completion and there are hopes for the installation of a 10m. volt Van de Graaf electrostatic generator, a major new piece of equipment for use in nuclear spectroscopy.

The synchrocylotron, which has a maximum energy of 400 MeV, was



View of the 9 MeV cyclotron which Sir James Chadwick used extensively when he was Lyon Jones professor of Physics at the university from 1935 until 1949

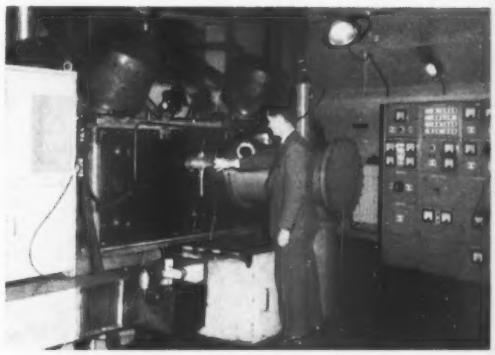
put into commission in 1954. At the time it was the largest in Western Europe. A university team headed by Mr. M. J. Moore supervised the work and Metropolitan-Vickers were responsible for its construction.

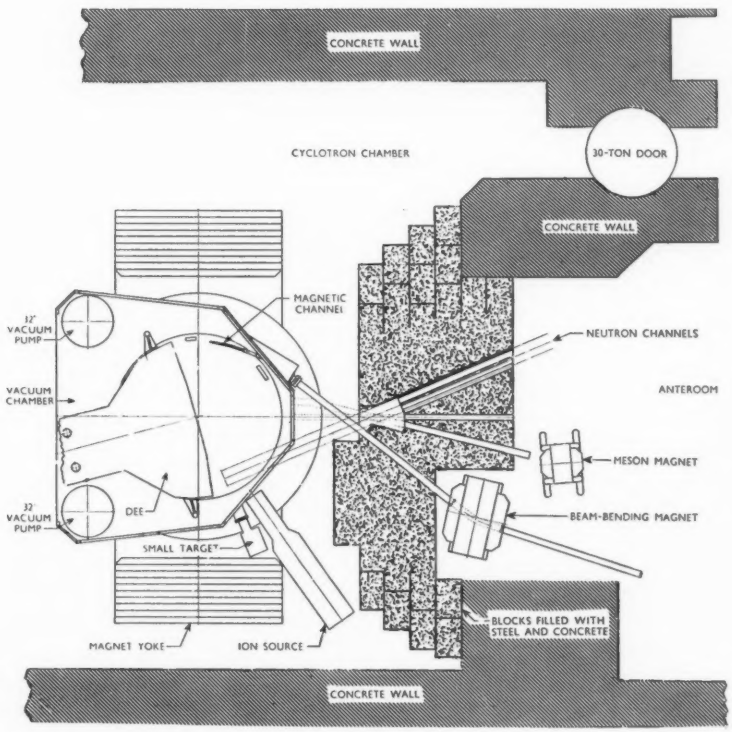
An extracted beam of 383 MeV protons with an intensity of about $1/30\mu A$ is available for experimental use, giving a flux of 4×10^{10}/protons /cm²/sec. Protons are successfully extracted by means of magnetic deflectors and magnetic channels.

Current research with the synchrocyclotron includes investigations into the properties and behaviour of pi and mu mesons. One study is of the parity problem that arises with the double decay of pions. Others are of meson induced fusion and of the interactions of particles with pions in liquid hydrogen.

Rather as to be expected, the synchrocyclotron tends to dominate the laboratory and the work carried out there. This does not mean, however, that the work on nuclei properties and the spectroscopic investigations carried out with the less spectacular apparatus is any the

(*Above*) **The synchrocyclotron building.** (*Below*) **The rotating condenser. To the right is the local control board. Only certain operations can be carried out from this and it is impossible to start up a beam with it**

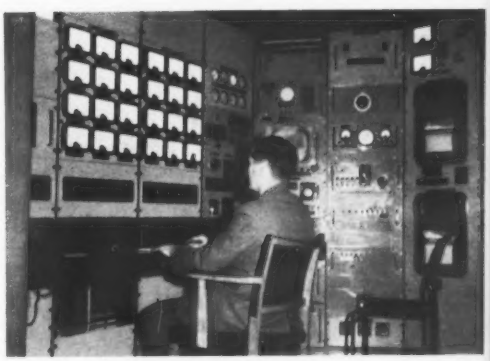




Description of Synchrocyclotron Building

The building in which the cyclotron is housed is of reinforced concrete and comprises an anteroom, cyclotron room, a basement with auxiliary equipment room and miscellaneous rooms above. The basement and one side of the cyclotron are bounded by solid sandstone rock, out of which they were excavated, and the remaining sides have 6 ft thick concrete walls with additional packed sandstone and brick walls to a thickness of several feet. The foundations of the cyclotron magnet are at the basement floor level and the magnet rises some 22 ft to within 2 ft of the cyclotron room ceiling. The vacuum pumping equipment and auxiliary plant are installed in the basement. The anteroom houses the magnet pole gap oscillator, rotating condenser, targets, magnetic beam deflector arc source, etc. It is divided from the cyclotron room by means of removable concrete filled steel bricks. Access to the cyclotron room is by means of a door that is electrically connected in such a way that a particle beam cannot be obtained unless the door is closed. The door consists of two concentric cylinders of steel erected vertically inside a 13 ft thick concrete wall. The inner cylinder just under 7 ft in diameter and 14 ft long is filled with sand and is free to move vertically within the other outer one, which is pierced opposite both sides with a 4 ft wide, 6 ft high aperture. A motor driven hoist mechanism is used for lifting the inner cylinder during closing and opening operations. Controls, alarms, indicators and monitoring equipment for the cyclotron are housed in a room 50 yd away from the machine, thus ensuring operators adequate protection from the hazards of high intensity radiation. For experimental and maintenance purposes much of the equipment can be started and controlled locally.

(*Above*) **The beam channel. A feature of this is the octopole magnet used for the strong focusing of meson beams.** (*Below*) **The main control room**



less important. Far from it, as Professor Skinner and his staff would be first to agree.

Most of the work is carried out by University staff and research fellows assisted by graduate students reading for their PhD degrees. In all, over 30 people are engaged in full time research in nuclear physics.

The number of undergraduates taking the university's honours in physics degree course is at present 33. Principally due to the extra accommodation the university will be able to provide when the new physics department is completed in the coming summer, this number is expected subsequently to rise to 50.

A large proportion of students who, pass through the laboratory either as undergraduates or graduates, take UKAEA appointments at Harwell, Risley or Aldermaston. Some go into industry—the laboratory provides an excellent background for the electronics scientists—and some enter the teaching profession.

Out of last year's batch of successful students at least five good men chose a schoolteaching career, but this was exceptional.

Extramural Course

An additional teaching facility provided at the laboratory is a week long course for qualified engineers and technicians who want an introduction to the fundamentals of nuclear energy. The course has been held now for three years and each time has proved to be extremely successful.

The laboratory has its own workshops for the construction of new equipment and for maintenance work. Over 50 skilled craftsmen and technicians are employed and facilities provided for almost any engineering job, whether it be heavy welding or the assembling of the most delicate electronics equipment.

Purposefulness

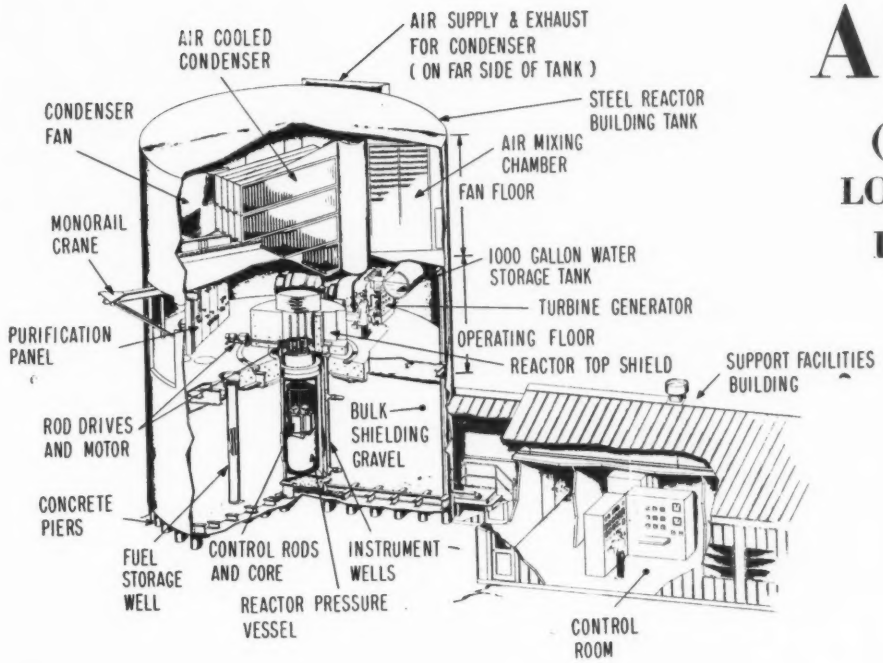
The visitor to Liverpool University's nuclear physics laboratory cannot but be impressed by its extreme orderliness and efficiency. The people who work there have an air of purposefulness about them which is not always found amongst university research staff.

It is in such an atmosphere that the Chadwicks, Cockcrofts and Rutherfords are bred and nurtured, though the large machines of the present day are a far cry from the " string and sealing wax " equipment of Rutherford's early day's. Though no one of quite their brilliance has yet emerged, there are many very promising young scientists in the world who owe a considerable amount to their Liverpool background. There is Dr. A. V. Crewe, for instance, recently appointed head of the particle accelerator division of Argonne National Laboratory, who was responsible for the design of part of the synchrocyclotron. Another is Dr. A. W. Merrison, a member of the CERN team which recently announced an important discovery made on the synchrocyclotron at Geneva. He was for several years at Liverpool as a research fellow and lecturer. The high energy research work at the laboratory is led by Prof. J. M. Cassels, one of the most outstanding of the younger physicists in the country. Much of the credit of the success of the laboratory in this field is, in fact, due to him.

Professor H. W. B. Skinner, FRS, Lyon Jones Professor of Physics and head of the laboratory

(*Above*) **The workshops attached to the laboratory. All manner of engineering work is undertaken here**

(*Left*) **Model of the new physics department teaching block, designed by Basil Spence and Partners**



ALPR

(ARGONNE LOW POWER REACTOR)

A POWER HEAT PACKAGE UNIT

In 1955, the American Department of Defence notified the Atomic Energy Commission of the need for an air-transportable, nuclear power plant capable of supplying about 200 kW of electricity and 400 kW of space heat. The plant was to be the main power source at a small remote installation such as a DEW-Line radar station in the Arctic. Six reactor concepts were analysed, and that for a prototype "packaged" power plant with a heterogeneous boiling water reactor submitted by the Argonne National Laboratory was selected for development. Known as the Argonne Low Power Reactor (ALPR), the prototype, which is at the Reactor Testing Ground in Idaho, was recently dedicated.

THE Argonne Low Power Reactor (ALPR) is a direct cycle boiling water reactor fuelled with enriched uranium and moderated and cooled by the natural circulation of light water. It has a design output of 200 kW of electricity and 400 kW of heat.

Meant for use in remote areas it will operate continuously for three years on a single loading. Simple and reliable to operate and maintain it also requires little supervision, automatic controls being installed.

An important feature of the reactor is that it is easily transportable by plane. No single component weighs more than 20,000 lb and is no more than 20 ft × 7 ft × 9 ft in dimensions.

On-site construction is simple and the unit is designed to be built on any terrain. Excavation for the reactor shell is unnecessary; the reactor is mounted on a series of concrete piles supported on a concrete slab foundation that simulates the pile support construction that would normally be used in Arctic regions.

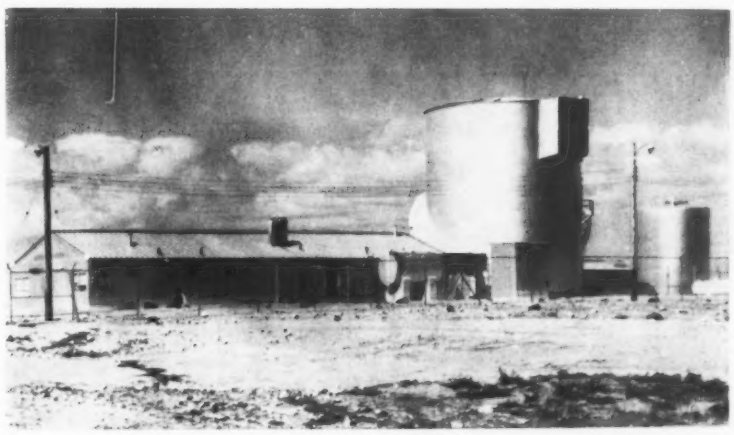
Biological shielding is provided by the use of ordinary gravel.

A new aluminium-nickel alloy, called X-8001 and developed by the Argonne National Laboratory, was used extensively in the construction of the prototype. Fuel elements are clad in X-8001 and the alloy was used to fabricate most of the reactor core.

The building that houses the ALPR is a circular, continuous-welded steel tank, 38 ft 7 in. in diameter, extending 50 ft above grade.

On Concrete Piles

The bottom of the tank rests on concrete piers 2 ft above grade. This creates an air space that reduces the



View of the ALPR site at the National Reactor Testing Station in Idaho

thermal heat transfer into the ground below the tank which, at an Arctic installation on permafrost, must remain frozen.

The tank serves as a weather shell around the structural steel framework that was erected inside of the tank and independent of it. The building has two floor levels: the operating floor is 19 ft 4 in. and the fan floor is 32 ft above the tank bottom.

Embedded in Gravel

The reactor pressure vessel is centrally located below the operating floor. Here also are three fuel storage wells, a reactor water retention tank, a purification vault, two storage sumps, and various instrument wells, ducts and piping. All these components are embedded in gravel that serves as a radiobiological shield. The gravel fills the bottom of the tank to within 2 ft of the operating floor.

The operating floor is of $\frac{1}{4}$ in. steel plate. The top of the reactor is further covered with movable shielding. Between the operating floor and the fan floor are the turbine-generator, a 1,000 gal water storage tank, control panels, two feedwater pumps, the hot well, a boron injection system, parts of the purification system, the overhead cranes, and other equipment.

Access to the building is by an enclosed stairway, an emergency open stairway, and a cargo door in the tank wall, all leading to the operating floor.

Access to the fan floor is through a hatch from below and an air lock. This floor contains the main air-cooled condenser with its fan, an air-mixing chamber, and ductwork. Condenser air is supplied and exhausted through an opening in the tank wall. An equipment hatch can be opened in the metal panel floor.

The main control room is in the Support Facilities Building, which is connected to the reactor by a passageway and the enclosed stairway. The Support Facilities Building also houses offices, workshops, training facilities, and simulated loads for the generator and space heating system.

Steam Generation

Saturated steam is generated in the reactor vessel at 300 lb/sq.in. and nearly 420°F.

Water level is held constant in the pressure vessel by an integrating three-element control system to

View of the ALPR tank, emergency exit and a stairway. A section of the air cooled condenser is being hoisted into the the tank

ensure steady operation and complete immersion of the reactor core. This regulates the feedwater flow to the reactor automatically by: (1) simultaneously measuring the water level, the steam flow, the feedwater flow; (2) integrating the electrical signals from the measurements; and (3) electrically adjusting the feedwater flow valve. Thus, under steady-state conditions, feedwater flow exactly equals steam flow.

Cooling Cycle

Feedwater enters the reactor through a spray ring surrounding the core, flows down the circular annulus around the core, and mixes with the downcoming water, making it slightly cooler than the rest of the core. This phenomenon, plus the lighter weight of the coolant in the steam-filled channels within the core, causes natural circulation of the water upward through the core. For every pound of steam produced, roughly 120 lb of water are circulated through the reactor.

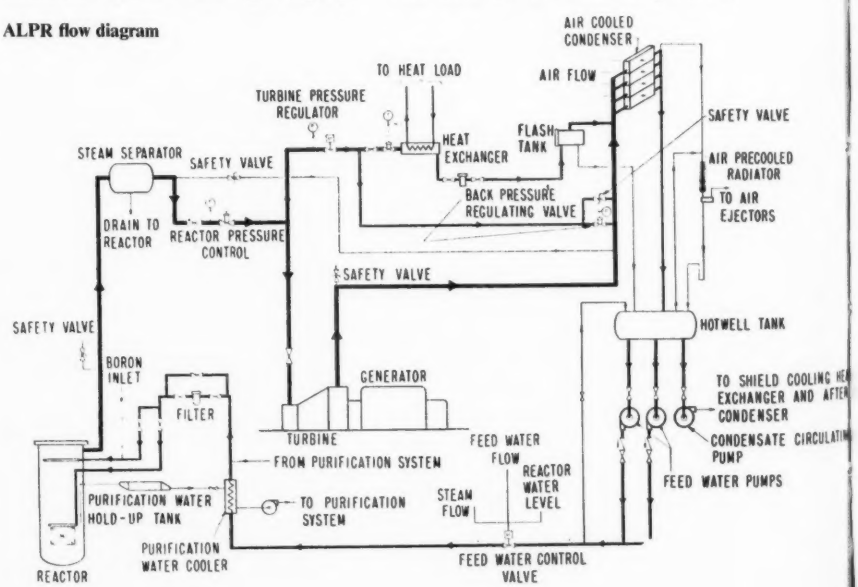
The ALPR generates steam at a rate of 9,020 lb/hr, corresponding to a reactor heat output of slightly less than 3,000 kW.

All returned feedwater is filtered; otherwise, irradiated corrosion products carried over by the steam might contaminate the conventional external system, such as the steam turbine, piping, etc., making maintenance and operation difficult. Five gal/min of the water in the reactor pressure vessel are continually pumped through a purification system to maintain high purity (total solid concentration is expected to be less than 2 parts per million).

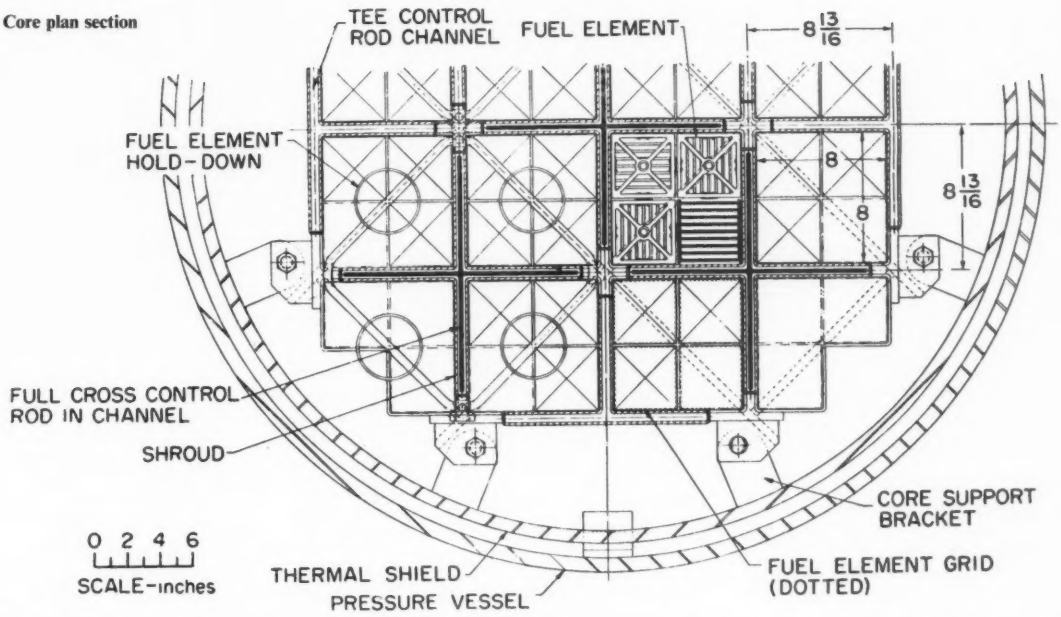
Vessel Data

The reactor vessel, built by Lasker Boiler Works, of Chicago, is fabricated from Type SA-212, Grade B Firebox steel, $\frac{3}{4}$ in. thick, clad with $\frac{3}{16}$ in. Type 304 stainless steel. The cover plate is 8 in. thick and is also stainless-steel-clad. The vessel measures $14\frac{1}{2}$ ft between the inside surfaces of the top and bottom heads and 4 ft 6 in. outside dimension. It was designed for 400 lb/sq.in. gauge at 450°F. water-and-steam temperature with 500°F. metal temperature.

ALPR flow diagram



Core plan section



The bottom is elliptical; the top cover is flat.

The top cover plate has nine 6 in. nozzles to accommodate control rod drives and two smaller nozzles for water level indicating controls. The nozzles provide access to the core for loading and unloading without removing the head.

Five Inlets

The vessel has internal base pads to support a thermal shield, which in turn supports the core structure. There are five connections through the wall of the vessel for feedwater, cooling water, a steam outlet, water purification, and boron injection. Two of these lines lead to an upper and lower spray ring.

The vessel is insulated with 3 in. of magnesia, surrounded by a protecting steel jacket.

(*Below*) ALPR fuel plates. Top one is the fuel bearing alloy which is pressed into the picture frame plate underneath. This is then sandwiched between the X-8001 plates on either side. (*Right*) Gravel for biological shielding

The entire vessel assembly is suspended by its top flange which rests on a support cylinder. The support cylinder, in addition to supporting the vessel, furnishes radiation shielding. It has a blanket of lead 1¼ in. thick around it; copper cooling coils embedded in the lead remove gamma heat. The lead is contained in a ¼ in. steel jacket. At core level the support has additional shielding in the form of a 1¼ in. thick steel band.

Boral Plates Used

The entire support cylinder and vessel stand on structural steel at the bottom of the reactor building.

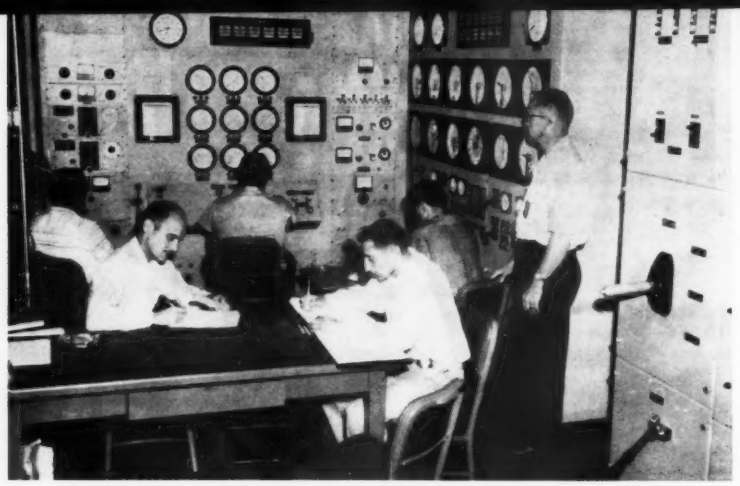
In addition to shielding already mentioned, the reactor and support cylinder are surrounded by gravel, which forms the main biological shield. Boral plates are used below the reactor. Steel shot and boric oxide are mixed with gravel and sand below and above the reactor. Concrete top shielding of the operating floor is cast in removable sections. A removable masonite and steel laminated shield covers portions of the concrete.

The core of the reactor consists of fuel assemblies and control rods fitted into a support and shroud structure. The support is an interlocking, welded-bar lattice composed of four 42 in. lengths of X-8001 2½ in. wide and ½ in. thick. The bars are notched to interlock in a 90° criss-cross pattern; all junctions are welded.

A system of extruded cross and T-shaped stanchions cut to precise lengths also are notched to interlock with the lattice junctions in exact vertical positions. This provides the main structural skeleton of the core support. The four pairs of open ends on the lattice sides are closed off by additional welded support bars. The eight outside corners of the lattice are welded to eight blocks of the same alloy 2½ in. × 3½ in. × 2 in. which are the support pads.

The Shroud

The shroud consists mainly of $^{5}/_{32}$ in. thick sheet stock, approximately 62 in. long and 16 in. wide, formed lengthwise into large angle sections. An arrangement of equally-spaced holes, 2 in. in diameter are



Control room of the ALPR

bored in these sections to provide an efficient water circulation system within the shroud and to cool the control rods. The outer enclosure is not perforated.

Each pair of angle sections is flush-riveted to the vertical cross and T stanchions of the core support to form 12 boxes (each to contain four fuel elements) at the centre and sides. Each box is square in cross section; the four corner boxes are contoured to contain three fuel elements each. The sides of these boxes serve as shrouds to define the control rod channels. There are five full cross channels and four T channels that can be used if necessary.

Like Egg Box

Welded at the bottom inside each box section is a system of egg-crate shaped supports to seat the bottom end fittings of fuel elements.

The core support and shroud rest on and are fastened to an arrangement of eight support brackets welded to the thermal shield. Six brackets have hold-down bolts that fit through the support pads of the core support and shroud. The remaining two brackets have special aligning pins that fit through the remaining two support pads to align and orient the core support.

The nuclear and mechanical design of the fuel assemblies for the 3 year operating lifetime resulted in a core structure consisting of 16 boxes containing a reference loading of 40 fuel assemblies (the maximum possible is 59).

Each assembly, $34\frac{1}{2}$ in. long $\times$ $3\frac{7}{8}$ in. square, is composed of a locating fitting at the lower end, 9 fuel plates, two side plates, and a top fitting equipped with a gripper pin for fuel-handling.

The top fitting consists of an extruded spider section welded at the inside corners to an extruded rectangular section to form a unit. The spider section at top dead-centre is drilled and tapped to take a corrosion resistant stainless steel gripper pin. A window machined out of each side of the rectangular section takes a stainless steel spring insert. The springs provide fuel element spacing and alignment and are riveted to the section. One large, over-size rivet is used to identify the side plate to which a boron-10 side strip has been attached.

Fuel Plate Design

Each fuel plate is bent lengthwise on both sides to form a flange. After bending, the ends are machined to provide exact spacing for the water channels between plates. By means of a tailored jig, the nine plates are spot welded to the side plates.

The bottom fitting is an extruded rectangular section machined to fit the fuel element support.

Except for minor items such as stainless steel fuel element gripper pins, rivets and spacer springs, the core is fabricated of X-8001 aluminium-nickel alloy.

Control rods are made of cadmium, a neutron-absorbing metal, and X-8001 aluminium-nickel alloy.

Five Control Rods

The alloy is employed to clad the cadmium and to give wear resistance and structural rigidity to the control rod. Above the absorber section, the alloy is used for the follower material. The rod, weighing 49 lb is connected to the drive mechanism by a stainless steel ball-joint end fitting.

Five cross-shaped rods, $14\frac{3}{4}$ in. $\times$ $14\frac{3}{4}$ in. $\times$ approximately $\frac{1}{4}$ in. thick (cadmium .060 in., aluminium .080 in.) are used for normal operation. Four T-shaped rods are available for larger core loadings.

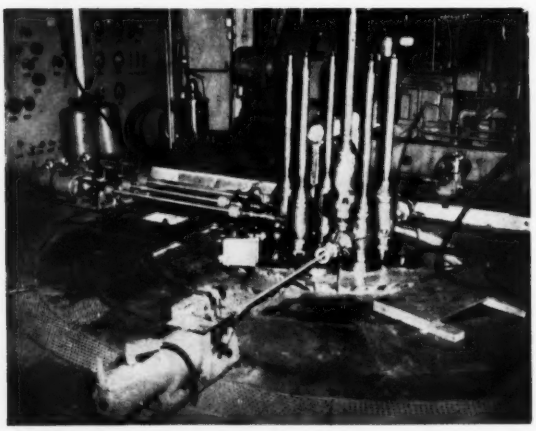
Because environmental conditions and service requirements of the Argonne Low Power Reactor are severe, the designers have decided that: (1) all instrument signal transmission and control actuator functions should be accomplished electrically, and (2) instrumentation should be as simple and dependable as possible using proved economical components.

For Future Needs

Much instrumentation in this prototype, however, is for collecting data needed to design future plants in which the additional equipment would be unnecessary.

In the control room, instruments and controls are segregated on a process control panel and a reactor control panel.

Information in this article was supplied by the Argonne National Laboratory, the U.S. Atomic Energy Commission and the U.S. Army Corps of Engineers.



Control rod drives and motors

ALPR

Specification Sheet

General Design

Reactor heat output	3,000 kW
Turbine-generator rating	300 kW
Frequency	60 ± ½ cps
Voltage	120/208 ± 5 per cent.
Phase (4-wire)	3
Power Factor	0.8
Design domestic heat	1.3×10^3 B.t.u./min
Steam production	9,020 lb/hr
Operating pressure	300 lb/sq.in. gauge
Operating temperature	420°F.
Feedwater temperature (hotwell)	134°F.
Standby equipment capacity (diesel electric)	60 kW
Ambient site temperature	—60°-60°F.
Wind velocity (maximum)	125 mile/hr
Building height (maximum above ground)	50 ft
Building site (simulated)	Permafrost
Site materials for construction	Local gravel

Fuel Design

Core	
Horizontal cross section	
Reference loading (40 assemblies)	28 in. × 28 in.
Maximum loading (59 assemblies)	33 in. × 33 in.
Fuel loading	
40 assemblies, U^{235}	14.0 kg
59 assemblies, U^{235}	20.65 kg
Metal-to-water ratio	0.5
Fuel Assembly	
Over-all dimensions	$3\frac{7}{8}$ in. × $3\frac{7}{8}$ in. × $34\frac{1}{2}$ in.
Weight, U^{235}	350 gm
Number plates	9
Wt. B^{10} in boron strip per assembly	0.4 gm
Wt. per cent. B^{10} in boron strips	0.45
Fuel Plate	
Over-all dimensions	0.120 × $3^{25}/_{32}$ × $27^{13}/_{16}$ in.
Cladding	0.035 in.
Meat dimensions	0.05 in. × $3\frac{1}{2}$ in. × $25^{13}/_{16}$ in.
Meat volume	74.0 cm^3
Wt. aluminium in meat	200 gm
Wt. U^{235}	38.9 gm
Wt. U^{238}	3.8 gm
Wt. per cent. Uranium in meat	17.6
at. per cent. Uranium in meat	2.2

Nuclear Data

Average thermal flux in fuel at full power (fresh reactor)	7.5×10^{12} n/(cm^2) (sec)
Max/Avg flux ratio in hot fresh reactor:	
Radial	1.6
Control cell	1.3
Axial (control rods out)	1.3
Axial (control rods halfway in)	1.7
Reactor (control rods out)	2.7
Reactor (control rods halfway in)	3.5
Reactivity changes, per cent. k:	
Temperature (cold→operating)	—1.5 to —2
Xe + Sm	—3
Steam Voids	—1.3 to —2
Xenon Override	—1 to —1.5
Neutron lifetime (sec)	4 to 8 × 10^{-5} (over range of core conditions)

Heat Transfer and Fluid Flow

Average power density in core coolant	17.5 kW/litre
Steam flow at 3,000 kW	9,020 lb/hr
Average steam voids in heated channel	9 per cent.
Average steam voids in moderator	7 per cent.
Exit steam quality	0.85 per cent. moisture
Water recirculation ratio (lb water/lb steam)	130
Feedwater inlet temperature	175°F.
Subcooling at channel inlet	1.8°F.
Average boiling length of core	20 in.
Total heat transfer area per 40-element core	475 ft^2
Average heat flux at minimum loading	21,500 B.t.u./hr/sq.ft
Average fuel temperature at centre line	450°F.
Average surface temperature plates	440°F.

Pressure Vessel Design

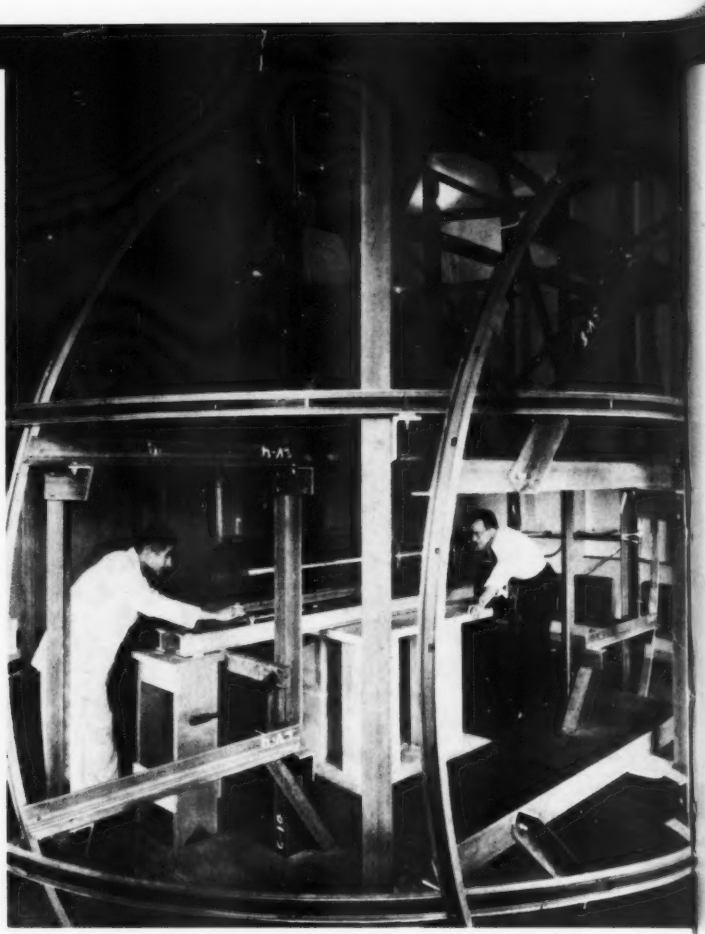
Diameter, OD	4.5
Wall thickness:	
Base material	$\frac{3}{4}$ in.
Stainless steel clad	$^3/_{16}$ in.
Height (less head)	$14\frac{1}{2}$ ft
Design pressure	400 lb/sq.in. gauge
Thermal shield	$\frac{3}{4}$ in. stainless steel
Pressure relief size and settings:	
First stage (to condenser)	2 in.—350 lb/sq.in.
Second stage (to atmosphere)	2 in.—385 lb/sq.in.
Level of water above core	4 ft—3 in.
Total weight (empty)	26,000 lb
Average volume of steam dome	80 cu.ft
Total weight of contained water	6,000 lb
Maximum thermal stresses due to gamma heat in vessel	750 lb/sq.in.
Maximum thermal stresses due to gamma heat in cover	600 lb/sq.in.
Design stress	14,000 lb/sq.in.
Type of closure	Double gasketing with leak-off
Design life	20 years
Water clean-up circulation rate	3 gal/min

Control Rod Design

Number of cross rods	5
Additional spaces for tee rods	4
Spacing	$8^{13}/_{16}$ in.
Length of cadmium section	32 in.
Thickness:	
Cadmium (meat)	0.060 in.
Aluminium-Nickel alloy (clad)	0.080 in.
Total travel	31 in.
Scram time	<2 sec
Withdrawal (~3 in./min)	0.01 per cent. k/sec
Weight of control rod	
Cross rod	49 lb
T-rod	37 lb

The Reactor was officially dedicated on December 2nd, 1958

Illustrated on the right is the apparatus with which U.S. scientists re-determined the gyromagnetic ratio of the proton—a fundamental physical constant of widespread value in practical nuclear physics. Work leading to this revaluation is described in the following article, which is based on a paper presented at a recent conference on electronic standards and measurement held at Boulder, Colorado. The glass sphere illustrated below contains the distilled water used as a proton sample



GYROMAGNETIC RATIO of the PROTON

THE gyromagnetic ratio of the proton—a measure of its interaction with magnetic fields—has recently been re-determined by the U.S. National Bureau of Standards with a significant increase in accuracy. This result not only provides a better standard for magnetic fields but also makes possible more accurate values for many of the fundamental concepts of physics whose values depend upon magnetic field measurements. Examples are the electron charge-to-mass ratio e/m, the magnetic moment of the proton, and Planck's constant h.

The re-determination was made by R. L. Driscoll and P. L. Bender of the Bureau staff, using facilities provided by the Fredericksburg Magnetic Observatory of the U.S. Coast and Geodetic Survey.

A Sensitive Probe

The new value for the proton's gyromagnetic ratio will be especially useful in the design and development of scientific and industrial apparatus in which it is important to know accurately the spatial distribution of a magnetic field or to regulate it closely. Here the proton can be used as a very sensitive probe to determine magnetic intensity in terms of the precisely known gyromagnetic ratio. Problems of this sort arise widely in the use of scientific apparatus—cyclotrons, mass spectrographs, and beta-ray spectrometers—and in industrial equipment such as servo mechanisms and electromagnets.

Link for Standards

The present work was carried out as part of a broader programme which seeks to obtain more accurate values for important constants, such as the velocity of light, the acceleration of gravity, and the various atomic constants. These constants of nature, when determined to extremely high accuracy, provide invariant bases for the reproduction standards of many physical quantities such as length, time and electric current. They thus serve to lock present standards and units of physical measurements into the phenomena of science. Because the proton's gyromagnetic ratio is basic to the determination of many of these constants, it provides a connecting link between them and the accepted standards of measurement.

Like other atomic nuclei, the proton, or hydrogen nucleus, behaves as a small magnet. When placed in a magnetic field, it tends to orient its axis along the direction of the field. However, the proton is also spinning rapidly about its axis, and the resulting angular momentum causes it to act like a gyroscope. Thus, instead of lining up with the field, the proton actually precesses about the field direction. The ratio of the angular precession frequency to the magnetic field strength gives the gyromagnetic ratio.

In 1949, H. A. Thomas, R. L. Driscoll and J. A. Hipple made the first precise measurement of the proton gyromagnetic ratio, using as protons the hydrogen nuclei contained in a small water sample. Their result was combined with other data to give a more precise absolute value for the proton magnetic moment than had previously been possible. More accurate values were also obtained for a number of the fundamental constants of physics, such as the electron charge-to-mass ratio and Planck's constant.

Accuracy Impaired

In the 1949 measurement, the gyromagnetic ratio was determined by measuring the magnetic field and radio frequency required for magnetic resonance absorption in the proton sample. A strong magnetic

field of about 5,000 gausses was used, and its value was determined by finding the force exerted by the magnetic field on a wire carrying a known current. This magnetic field measurement was difficult and was the principal limitation on the accuracy of the result obtained.

Error Reduced

The present method reduces the error of the earlier one by a factor of four by using simpler techniques that have been developed since 1949. In this method the hydrogen protons in a water sample are caused to precess in a magnetic field, and the precession rate is obtained from the frequency of the voltage induced in a pickup coil surrounding the sample. The gyromagnetic ratio is then obtained as the ratio of the angular precession frequency to the field strength.

Increased accuracy is obtained by using a magnetic field that can be calculated to very high precision. This field is produced by an accurately measured current flowing through a solenoid whose important dimensions are known to one part in a million. However, as the field strength obtained in this way is only 12 gausses, spurious magnetic fields from other apparatus, electrical currents, or vehicles must be carefully avoided. For this reason, the measurements have been carried out at the Fredericksburg Magnetic Observatory of the U.S. Coast and Geodetic Survey.

The Observatory is about 10 miles south of Fredericksburg, Virginia, on a site chosen to be as free as possible from magnetic field disturbances. A separate non-magnetic building, with large coils for compensating the earth's magnetic field, was made available for the experiment. At this location man-made magnetic field fluctuations are negligible and corrections for variations in the earth's field can be obtained from the Observatory magnetograms.

Spherical Sample

The proton sample consists of distilled water contained in a glass sphere about 2 cm in diameter. The sample is placed in a strong magnetic field in order to build up a large magnetization of the protons along the direction of the magnetic field. It is then shot about 15 m through a pneumatic tube into the centre of the solenoid, within the non-magnetic building. With the sample in the solenoid, a short pulse of radio-frequency magnetic field near the precession frequency is applied to tip the magnetic moments of the protons so that they are left nearly perpendicular to the magnetic field direction. They then precess about the magnetic field direction at a frequency corresponding to the strength of the field.

The flux through a pick-up coil surrounding the sample changes at the same frequency at which the magnetization of the sample is precessing. The frequency of the induced voltage across the pick-up coil is measured accurately against standard frequency broadcasts by the Bureau's radio station, WWV, and the resulting value is combined with the magnetic field strength to give the proton gyromagnetic ratio.

Results Obtained

A preliminary value of $(2.67515 \pm 0.00001) \times 10^4$ radians/(sec gauss), uncorrected for diamagnetism of the water sample, was obtained for the proton gyromagnetic ratio in terms of the ampere as now maintained at the Bureau. The value obtained in 1949 was given as $(2.67523 \pm 0.00006) \times 10^4$ radians/(sec gauss). If the present result is combined with a recent determination by Driscoll and Cutkosky of the ampere as maintained at the Bureau in absolute units, the value becomes $(2.67513 \pm 0.00002) \times 10^4$ radians/(sec gauss).

The solenoid used in the proton magnetic experiments is shown here. On the right it has been moved to reveal the compensating coils used to make the magnetic field more homogeneous

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This was the shape of

f oil after radiation

Here was a problem of national importance. Lubricants were needed by the nuclear industry for reactor equipment, much of it subjected to radiation. Yet, like human beings, oils and greases were vulnerable to radiation. Oils darkened in colour and became coarse-grained solids (solidification being but one of a tangled skein of problems).

The Shell Group started working on the problems of lubricating under radiation conditions while most nuclear power stations were still on the drawing board. In fact, Shell was the first oil company to develop Atomic Power Lubricants, and the research that went into Shell A.P.L. is characteristic of the way Shell sets about doing things. A team of research workers was assembled at Shell's Research Centre at Thornton. Series of tests were carried out both in the B.E.P.O. pile at the U.K. Atomic Energy Authority Research Establishment, Harwell, and with Thornton's own Cobalt 60 source of radiation. In 1957, after four years of research, Britain's first range of Atomic Power Lubricants was on the market.

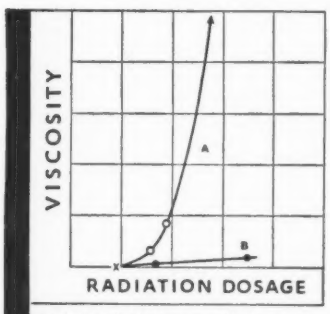
The moral of the A.P.L. story is that Shell research is supremely applicational. The Centre at Thornton is always ready to work with even the most specialised sectors of industry to produce the right oil for the job. If you and your organisation have any major lubrication problems, it will pay you to get in touch with your local distributor of Shell Industrial Lubricants.

The Research Story

In the hundreds of complex hydrocarbons examined, very different reactions to radiation were observed according to the configuration of the atoms in the molecules. When carbon atoms were arranged in long, straight chains, radiation caused these chains to link up with one another, giving highly complex structures of an entirely different nature from the original material. The first effect of this change was to cause a rapid increase in viscosity, ultimately giving rise to a solid rubber-like product.

For example, a high quality turbine oil conforming to BSS.489 receiving a dosage of 1.77×10^{18} neutrons/cm^2 was changed into an intractable solid—a clear demonstration that radically new lubricants were needed by the nuclear industry.

Shell Atomic Power Lubricants have a molecular structure that has proved itself very resistant to radiation. In fact it will withstand a radiation dosage four million times stronger than that which will kill a man—without ar ; significant change in structure or physical properties.



Relationship between radiation dosage and percentage increase in viscosity, cS at 100°F.
Oil A: high molecular weight long chain hydrocarbon. *Oil B:* Shell A.P.L. 731.

SHELL

ATOMIC POWER LUBRICANTS

another proof of Shell leadership in Lubrication

SWEDEN is at the moment much perturbed by a phenomenon which troubles other European countries, including Britain—the loss of scientists, who seek their fortunes on the other side of the Atlantic. Sweden hopes to stop the rot by spending more money on her universities, but is this a case of the closing of the door after the horse has bolted? Even in Britain there is much to be done if teachers are to be kept happy. Foolishly, some folk think this is purely a question of offering high enough salaries. Teachers, mercenary as they may be, are not quite so easily caught.

What many of them need is the incentive of research opportunities, and even though the government tried to sound the position some years ago, there are still many technical colleges and other teaching institutions where facilities are being wasted. Our nuclear industry could surely take advantage of the talent available in these institutions, even though it would not be advisable or even practicable to install in all of them research reactors and radiochemical laboratories.

Not every educational establishment can be sufficiently well endowed to own a reactor, even though it be a modestly-priced one like the L-77 which attracted so much attention at the Geneva Conference last summer. Placed on the open market by Atomics International at a figure which includes installation, transport, testing, and the operational training of personnel, this reactor represents the nearest to the poor man's research reactor so far produced. At Geneva the visitors were even able to operate this reactor after a few minutes of explanation, and to receive the Honorary Operating Certificate. This was clearly a showground piece of advertisement, for

'NUCLEARIST' writes . . .

while some highly-placed officials from the world's atomic energy commissions tried their skill, one successful operator was a mere child of six years of age.

And when the reactor has been bought, is all financial responsibility over? Clearly, the answer is no, as is shown by the recently inaugurated research reactor at Geesthacht, near Hamburg. After the 30 hr warming-up period, this reactor became critical at 04.45 hr on October 23rd, 1958, and now research can begin in earnest, once the laboratories have been completed and put into use. This reactor is of special interest, in view of the fact that it is the first in Germany to be the subject of an insurance policy. The Deutsche Kernreaktor Versicherungsgemeinschaft was formed in Cologne from 86 different assurance companies. This is a bold step, but a very necessary one. Where are the statistics on which to base the risk calculations? What premium has to be paid? What risks will result from an accident? These are questions to which there is no simple answer, nor any precedent upon which to work. Normal insurance calculations will be inapplicable for many, many years, and in fact may never prove of much value in reactor assurance.

The Karlsruhe research reactor is facing severe difficulties at present, and seems unlikely to be completed on schedule. The German government, faced with awkward questions in the Bundestag, has agreed to permit extra money to be allocated to the project, since quite obviously the original estimates were not realistic. Warnings have been given that safety must not be sacrificed for the sake of economy, and in spite of the fact that the government has given its assurances that there is no panic, there remains a big " but." This situation, together with the death of Professor Paneth, and the disastrous fire in one of the research institutions in which thermonuclear work was to be undertaken, must have set back Germany's nuclear progress a few pegs. May their doldrums be not too severe.

30 MW HEAVY WATER REACTOR

(*Continued from page 21*)

The main D_2O coolant or power circuit shown on the upper right of the flow diagram includes a pressurizer which regulates the pressure in the system by means of an electric heater and two steam generators. On the secondary side of these heat exchangers, 40 tons of saturated H_2O steam are produced per hour at a pressure of 11 atmospheres and a temperature of 183°C. This steam may be passed either to two condensing turbines with a total maximum electrical output of 5,900 kW or may be divided between the turbines and a steam transformer of 20 t/h capacity, which supplies the district heating system with saturated steam of 7 atmospheres pressure.

On the upper left of the flow diagram the moderator cooling circuit is depicted. As has already been noted, this circuit is under atmospheric pressure, and in order to avoid the possibility of damage it is strictly separated from the D_2O power circuit, as can be seen from the flow sheet. Both heavy water cooling systems are provided with auxiliary cooling circuits, by means of which the heat production of the reactor may be extracted both after a normal shut-down and in case of a failure in one of the main circuits. The complement of reactor circuits is made up by the reflector and shield cooling systems and by the heavy water storage systems.

All heat produced by the reactor system which is not converted to useful power is extracted by way of the main intermediate circuit and then given up to the river cooling water in the main cooler. The auxiliary D_2O cooling circuits are, however, in connection with a separate auxiliary intermediate circuit, in order that the reactor may be independently cooled either after shut-down, in case of a power failure or during maintenance work on the main circuits. The H_2O power circuit also belongs to this group of closed intermediate circuits, which all operate on demineralized light water.

The external circuits, finally, comprise a river water cooling system using water from the River Limmat, and the existing district heating system already mentioned.

WELDING

in the

Nuclear Industry

By
R. WECK, PhD, AMICE, AMIMechE
Director of Research
British Welding Research Association

JOINING plays a cardinal role in engineering production because almost every product of the engineering industry is made in parts which have to be joined. In nuclear engineering, where leakage cannot be tolerated, welding is the only joining process offering at least potentially the possibility of making joints to the exacting standards required. Basic decisions regarding the type, size and operating conditions of reactors must be strongly influenced by considerations of whether the required hardware can or cannot be fabricated by welding and whether there is a reasonable prospect of solving the welding problems involved in construction.

These problems arise in various ways. Existing processes may have to be adapted and modified to satisfy unusual requirements. Entirely new processes may have to be developed for materials which have not previously been used extensively in engineering. Even when well tried processes are applied to quite common materials the service conditions may be so severe or the requirements for quality, strength and corrosion resistance of the joints may be so unusual that extensive investigations are required. Mere size—such as the large reactor vessel—may involve design problems where extrapolation from past experience is no longer reliable. New structural forms—such as the spherical end of the vessel pierced by numerous charging nozzles—pose problems of design and fabrication not previously encountered in engineering. All these problems are welding problems, and the speed of progress in nuclear engineering is largely dependent on how successfully and how quickly some of them can be solved.

A great deal of research is going on, yet one wonders whether enough effort is devoted to problems likely to arise in the future simply because the effort needed to deal with the problems of the present is so prodigious. There was a time—and it is not so long ago—when it was believed that the limit of our research effort in any particular field was determined solely by the amount of money that could be made available. This is no longer true. The limit today is our technical and scientific manpower. It is the more important therefore that duplication of effort must be avoided. Companies in the nuclear power field must think very carefully whether the expenditure of technical brainpower to the solution of any particular problem is likely to produce a commercial advantage in the long run or whether it would not be better in their own and the national interest to co-operate with other companies working on the same problem.

When co-operative research associations were started by the Government in 1918 it was with the idea of providing firms who could not afford their own with co-operative research facilities. Today, when money at least in the nuclear energy field does no longer seem to be the limiting factor in research, co-operation may become a necessity even for large companies, at least over a certain section of the field, because of the limited resources of technical and scientific manpower any individual company can hope to deploy. By devoting too much of their available brainpower to problems of today and not enough to problems of the future firms may well find the return for their research expenditure disappointing in a few years time.

Machinery for such collaboration exists within the industrial branch of the UKAEA, and for welding problems within the British Welding Research Association. The problem of the brittle fracture of thick mild steel plate, for instance, is being investigated by the British Welding Research Association on behalf of all the companies with an interest in this field. There are many other welding problems where such collaboration is possible and desirable and where the advantage any individual firm may derive from finding a solution may at best be temporary and may be worth the expenditure of its own scientific manpower.

This special issue of NUCLEAR ENERGY ENGINEER, in drawing attention to the cardinal role welding research must play in the further progress of this new technology, must be warmly welcomed by all those who are concerned with the advancement of knowledge in this field.

WELDING — Special Feature

HEAVY PLATE TECHNIQUES

BRITAIN'S nuclear power programme has necessitated the construction of some of the largest vessels ever built. Moreover these massive vessels have been built to standards of perfection higher than ever previously contemplated, and their construction has involved complex problems of design and fabrication.

Generally speaking, the thickness of the plate used and the size of a container vessel for a gas-cooled reactor are directly related to the output of the power station. Both in the case of a conventional generating station and in a nuclear power station, an increase in efficiency requires the use of higher temperatures and pressures. Consequently pressure vessels of greater size and thickness have to be provided.

(*Above*) **A test weld in 3 in. thick plate for a pressure vessel to be installed in one of the nuclear power stations**

At Calder Hall, which is designed for a maximum heat output of 180 MW per reactor, the main reactor container pressure vessels are 37 ft in diameter, 72 ft high and are made of 2 in. thick plate. Views of the bottom dome and the shell of one of these reactor vessels in the course of construction are illustrated.

Thicker by 1-2 in.

Calder Hall, however, was designed by the United Kingdom Atomic Energy Authority as a prototype plant, and while it feeds electricity into the national grid, one of its main functions has been to provide practical experience in the operation of a nuclear power station. This experience has made possible a considerable increase in efficiency in the nuclear power stations at present being built for the Central Electricity Generating Board. The pressure vessels for these will be larger and thicker than those at Calder Hall, 3 in. and 4 in. thick steel plates being used for their fabrication.

For many years past 3 in., 4 in. and much thicker plate has been successfully welded under workshop conditions where facilities for positioning, preheating stress relieving, X-ray tests, etc., are readily available. The welding of a massive vessel with walls of very thick plate to X-ray standards on a remote

nuclear energy site, however, presents a very different problem.

It is unfortunately true that all the constructional steels at present in common use are liable to fail catastrophically in brittle manner under certain conditions of applied stress as the ambient temperature falls.

Tests show that at above about 20°C. many of these steels have reasonable impact strength and fracture under impact loading is of a ductile type. However, the impact strength usually falls sharply at temperatures below 10°C. Below, say, −30°C. it is negligible, and the fractured surfaces have a brittle appearance.

Brittleness Danger

The range of temperature over which the type of fracture changes from ductile to brittle in an impact test is known as the transition temperature range, and it can be regarded as an indication of the tendency of a steel to fail catastrophically in a brittle manner under service conditions. It has been shown that the higher the transition temperature range, the greater the susceptibility of the steel to brittle fracture at ambient temperature.

Engineers and metallurgists are well aware of the dangers of brittle fracture, and although the problem is still not fully solved, a number of empirical precautions can be taken to reduce the probability of its occurrence in practice. Thus, where a structure or vessel is likely to be exposed to embrittling conditions it is obviously prudent—if not essential —to specify the use of steel and weld metal which will have not less than a certain impact strength at a given sub-zero temperature. In order to guard against the possibility of brittle fracture during the construction of a nuclear reactor vessel, the steel plate and weld metal may be required to have an impact strength of not less than 35 ft/lb at −10°C.

Because of their massive size, these nuclear reactor container vessels normally have to be finally assembled and welded on site. Most nuclear power stations are sited in remote exposed areas, and construction has to proceed under difficult conditions in all kinds of wind and weather, in summer and winter temperatures.

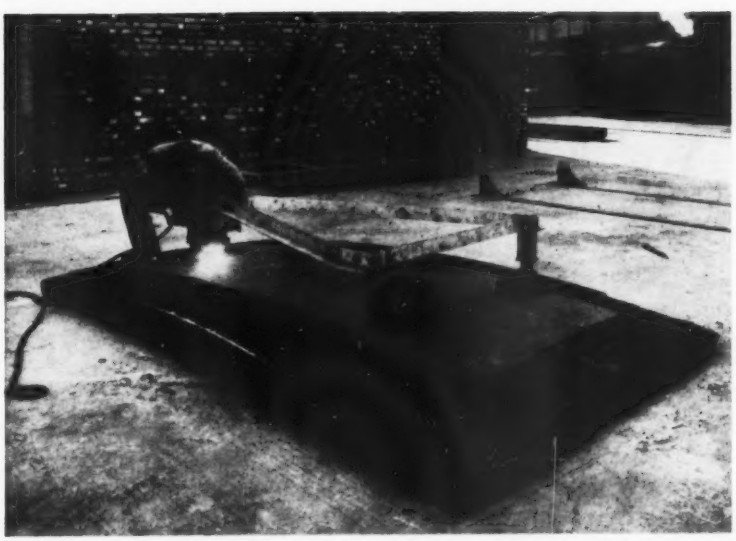
At Dounreay

One of the best-known examples of an exposed site is that of the Dounreay fast breeder reactor, which is situated on the lonely coastline of Caithness in the north of Scotland. The bottom half of the 135 ft diameter sphere for this reactor was constructed between July and December, 1955, and the top half between July and December, 1956, after some internal construction work had been done. In spite of very difficult conditions and low temperatures, the welding was successfully carried out with Murex " Fortrex 35 " electrodes.

However, the shell of the Dounreay sphere was constructed of plates only 1 in. to $1\frac{7}{8}$ in. thick. When plates 3 in. and 4 in. thick are used, further complications arise because an increase in the thickness of a steel plate (whether of mild or low alloy steel) is known to increase the likelihood of brittle fracture, and increase in thickness alone may raise the transition temperature by as much as 50°C. For example, a 1 in. thick plate of a particular steel may be satisfactory at −25°C., whereas a 3 in. thick plate of the same steel may not be safe from brittle fracture at +25°C.

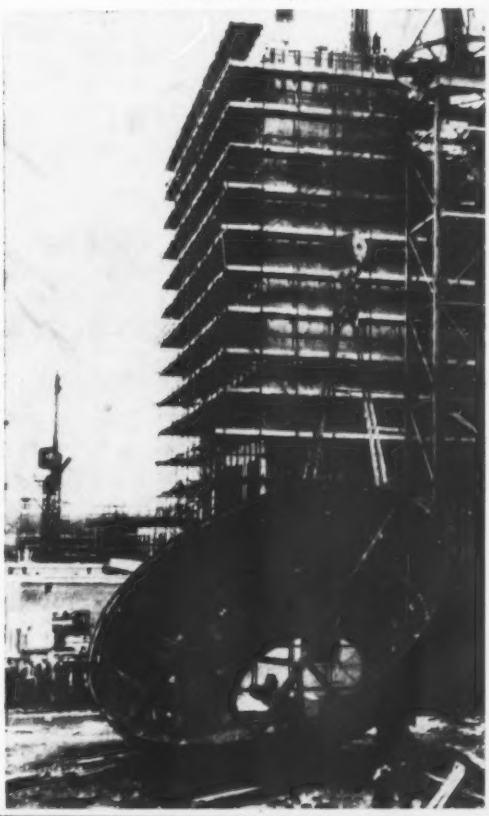
Irradiation Factor

When a reactor is in operation, the temperature of the container vessel is maintained at temperatures above the ductile/brittle transition temperature of the steel of which it is constructed. It has been shown, however, that neutron irradiation may raise the transition temperature of the steel by as much as 50°C. and so increase its susceptibility to brittle fracture. Although it is obviously essential that a massive vessel of this kind should not crack or split during construction, it is equally imperative that it should not fail during operation.



Thick plate for a reactor pressure vessel at Bradwell nuclear power station
Photo: Whessoe, Ltd.

The bottom dome of one of the reactor pressure vessels at Calder Hall
Photo: Whessoe, Ltd.



Bearing these points in mind, it would seem very desirable that the steel selected for use in the construction of a massive reactor vessel should have a transition temperature and/or an impact strength well above the required minimum. In addition, the weld metal used should have better impact properties than the wrought parent metal, because a fault in the welding technique could give rise to defects in the weld metal. As these might initiate brittle fracture, the impact strength of the weld metal should be adequate to prevent the propagation of a brittle fracture from such internal flaws.

Tests on 3 in. Plate

Some time ago, when it was decided that 3 in. thick plate would have to be used for large nuclear energy vessels, extensive tests were carried out in the Murex Laboratories with various commercially available standard electrodes which appeared suitable for this type of work. The results showed that none of these electrodes would consistently give the required impact properties at −10°C. throughout the whole section of the welded joint in 3 in. thick plate, although all but one of the electrodes met the requirements with ease in tests on 1 in. and 2 in. thick welds.

The tests involved the welding of a large number of 3 in. thick mild steel plates in various positions and the machining of an appropriate number of Charpy impact specimens from three levels through each weld. Each

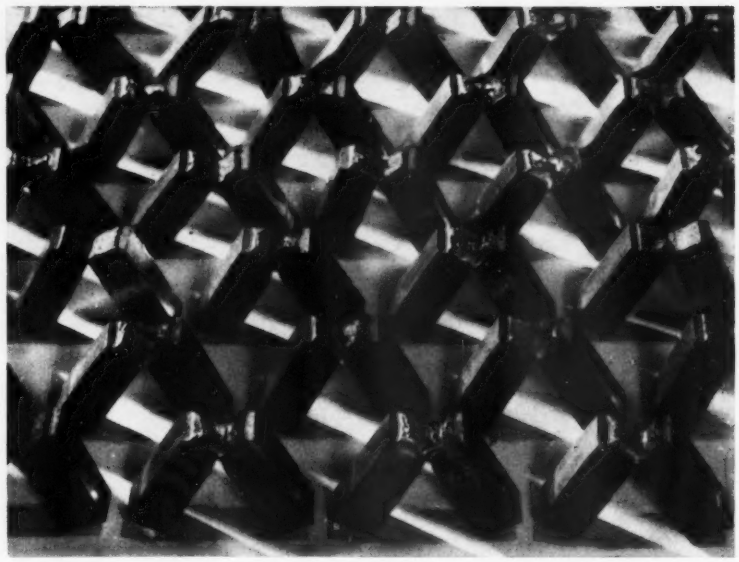
Welding 3 in. thick plate under test. Overhead position

welded test plate was stress relieved at 625°C. before machining the impact specimens, which conformed to the standard Charpy V notch specimen dimensions with the notch in the " top " surface.

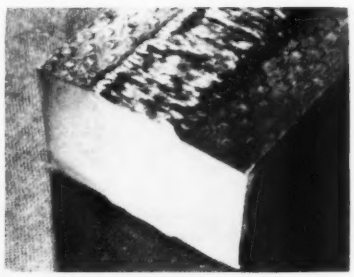
In view of the great importance of the matter, exhaustive tests were carried out involving the enormous task not only of welding a large

Welding 3 in. thick plate under test. Horizontal position

number of heavy plates but of machining out and testing over 1,000 Charpy specimens. As was expected, the results revealed a scatter in impact properties above and below an arithmetical mean, and while this was quite typical of weld metal, the lowest results indicated that certain



(*Top*) Some of the more than 1,060 Charpy impact specimens made during the tests on thick weld plate. (*Bottom*) A section through the weld of one of the many heavy plates which were tested



regions of the 3 in. thick welds were deficient in impact strength.

The results also confirmed tests made by an independent investigation showing that welding position has an effect on the weld metal impact properties obtained with any given electrode. As welding in all positions is normally inevitable in the construction of reactor pressure vessels on site, the only conclusion which could be drawn was that standard rutile and low-hydrogen electrodes should not be recommended for this particular application.

New Electrode

To sum up, the investigation proved:—

(1) That even the best electrodes, such as " Fortrex 35," which are capable of depositing weld metal having good impact resistance at sub-zero temperatures when used for welding 1 in. and 2 in. thick plate,

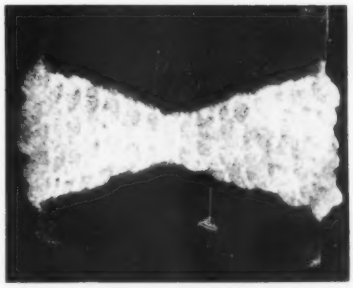
are not necessarily equally suitable for plate of 3 in. and more in thickness.

(2) That because of the normal scatter in impact properties the weld metal for thick plate welding should have a range of impact properties appreciably higher than that obtainable with existing electrodes.

Accordingly, to meet the special requirements of the welding of extra-thick plate for nuclear energy applications, a new Murex electrode known as the " Fortrex 35A " has been developed in the Murex laboratories. This development has demanded very considerable and intensive research work involving a study of the factors affecting the impact properties of weld metal deposited in deep vee preparations, an examination of the fluxing and deoxidation behaviour under such conditions, and an investigation of the nature of the grain boundaries and the metallurgical structure of the deposited weld metal.

Versatile

" Fortrex 35A " is a basic low-hydrogen electrode suitable for use in all positions and capable of depositing homogeneous and sound weld metal having high impact resistance throughout the whole thickness of welds made in 3 in. and 4 in. thick plate. Typical test results



Photomacrograph of section through a weld made with Murex " Fortrex 35A " electrodes in 3 in. plate

are shown in the table, from which it will be seen that the impact properties of " Fortrex 35A " are vastly superior to those of the standard electrodes shown in the table and that the figures are often twice or three times as high as the usual requirement of 35 ft/lb at −10°C. It will also be appreciated from these figures that the general level of the scatter band with " Fortrex 35A " electrodes is appreciably higher than that obtained with standard electrodes.

Typical tensile test figures given by all weld test specimens machined from deposits made with No. 6 gauge " Fortrex 35A " electrodes are as follows:—

Ultimate tensile strength .. .. 31.6 ton/sq. in.
Yield strength .. 29.2 ton/sq. in.
Elongation over 1½ in. gauge length .. 39 per cent.
Reduction of area 76 per cent.

It is also of interest to note that Charpy V notch impact tests have been made at eight temperatures between 20° and −70°C. with the weld metal of " Fortrex 35A " electrodes machined from four levels of a 4 in. thick horizontal-vertical weld, and the transition curves produced show that the weld metal has good impact properties throughout the whole thickness of a 4 in. joint even at temperatures below −10°C.

High Quality Reached

Finally, the " Fortrex 35A " electrode has all the advantages of the standard " Fortrex 35 " type. It is an all-position electrode; it is simple to use, slag removal is easy, and the radiographic quality of the weld metal is sound. It is also important to note that it is a special electrode for extra-thick plate welding only, and it does not supersede the standard " Fortrex 35 " electrode for normal applications requiring basic low-hydrogen electrodes. For its special purposes, however, it sets a standard of quality higher than any yet achieved in the welding industry.

The Editor is indebted to the editor of *The Welder* for his help in the presentation of this article.

TABLE.—RESULTS OF IMPACT TESTS

Plate Thickness	Electrode Type	Welding Position	Charpy V Notch Results at +18°C. at Position*: 1 (ft/lb)	2 (ft/lb)	3 (ft/lb)	Charpy V Notch Results at −10°C. at Position*: 1 (ft/lb)	2 (ft/lb)	3 (ft/lb)
3 in.	**Standard Types**							
	A, B, C Basic low-hydrogen	Vertical-up	15	40	36.5	27	31.5	25
			63	69	63	44	41	42.5
			35	40	67	44	25	26.5
	D Rutile		30.5	42.5	9.5	19	32	10
	C Basic low-hydrogen	Horizontal-vertical	46	41	76.5	60	41	25
	D Rutile		49.5	42.5	46	30	14	11
	" Fortrex 35A "	Downhand	205	117	106	129	62	94
		Vertical-up	98	88	90	65	53	84
		Horizontal-vertical, 40° preparation	170	170	123	132	141	115
		Horizontal-vertical, 45° preparation	100	120	140	129	79	87
		45° vertical, semi-overhead—semi-vertical-up	166	92	106	78	51	95
		Overhead	126	98	146	121	70	62
4 in.	**" Fortrex 35A "**	45° semi-horizontal-vertical—semi-overhead	162	178	178	125	90	94

*Positions 1-3 are at different levels throughout thickness of plate

WELDING—Special Feature

Problems of the REACTIVE METALS

NIOBIUM
TANTALUM
ZIRCONIUM
BERYLLIUM
MOLYBDENUM

by F. G. Cox, PhD, BSc, ARCS, DIC

THE usefulness of a metal often depends on how satisfactorily it can be joined to itself and to other materials. Interest has increased in the reactive metals such as tantalum, niobium, etc., and this has led to investigations of methods of joining these metals, particularly with regard to homogeneous fusion welding.

Tantalum is of great importance in the chemical equipment field because of its excellent resistance to corrosion by acids and other media in applications where thermal conductivity is also important. Despite the high cost, the use of tantalum is expanding because the initial cost is amply repaid by long life and efficiency. Some units have been examined after 10 years service and have shown no corrosion at all.

Niobium has come to the fore because of its use in the experimental reactor at Dounreay where high creep strength at elevated temperatures, resistance to corrosion by liquid metals such as sodium and potassium and compatibility with uranium at elevated temperatures are important.

Submarine Material

Zirconium is another metal of interest in nuclear energy fields. It has a high corrosion resistance, low neutron capture cross-section and has become established in its application in the U.S. pressurized water reactors used principally in the submarine *Nautilus* and later vessels.

The reactive metals are attacked vigorously by atmospheric gases at only moderately elevated temperatures—temperatures far below their melting point—and it is essential to protect them from contamination when welding to avoid loss of ductility and other valuable properties such as corrosion resistance. The usual welding method is the argon arc process in which protection is given to the weld metal by a blanket of argon gas. This process, with suitable modifications, is an excellent general purpose tool.

Resistance welding has also been used to advantage, particularly for the thinner sizes, and in this case protection is afforded by virtue of the fact that the weld nugget is surrounded by the metal being welded.

Back Protection Vital

Both these methods will be described in some detail, followed by a discussion on some of the more recent welding methods which have been developed and which may be applicable to the reactive metals.

The most important modification that must be made to the standard argon arc welding process, as used for welding aluminium, magnesium and stainless steel, when welding niobium, tantalum, etc., is to allow for protection of the back of the weld as well as the face. The result of a lack of such protection is well shown in Fig. 1, where the back of a weld made in zirconium with satisfactory protection is compared with the puckered oxide skin of a weld inadequately protected. Such a weld would lack any ductility. A series of jigs, designed for welding titanium and allowing for complete protection to the back of the weld have been described by Taylor and Moore.[1]

Protection to the face of the weld is adequately provided by the stream of argon from the normal torch when welding sheet in thicknesses up to about 0.05 in. Direct current welding gives better results than alternating current due, it is thought, to the fact that direct current gives a deep narrow pool better protected by the argon shield than the shallower broader pool of the a.c. arc.

For rather similar reasons machine welding has definite advantages over manual welding in that the pool and the argon blanket progress steadily along the weld without the oscillations which are unavoidable with hand welding—" puddling " should definitely be avoided. That much higher welding speeds can be used when operating with a machine is an additional advantage as the metal is molten for a much shorter time. Trailing shields have been suggested, but do not seem to be necessary except perhaps for the most critical work.

No Filler Wanted

The preferred joint with the reactive metals is the straight butt joint with no filler rod. Filler rod is best avoided because it will oxidize outside the protection of the argon gas, and the oxide will be fed into the

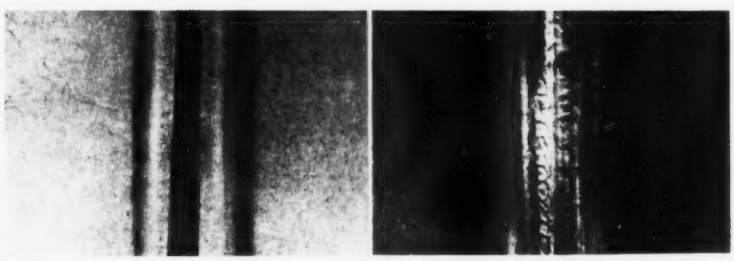


Fig. 1.—Effect of adequate and inadequate protection to underside of a weld in zirconium

Fig. 2.—Argon box for welding reactive metals

with argon. If satisfactory results are to be obtained, it is essential that the argon should be very low in impurities such as oxygen and nitrogen. In general, commercially available pure argon is satisfactory, for instance British Oxygen Co. lead seal grade or Saturn Black Label.

Portable shields, affording complete protection to large weldments have been proposed[1,2], but it would be difficult to design one that is universal. A reactor core tank has been fabricated in a zirconium base alloy (Zircalloy II), welding with the aid of precision shields constructed to conform with the geometry of each weldment.[3] Fig. 3 shows a selection of such shields and Fig. 4 shows one in use on the spherical shell of the vessel.

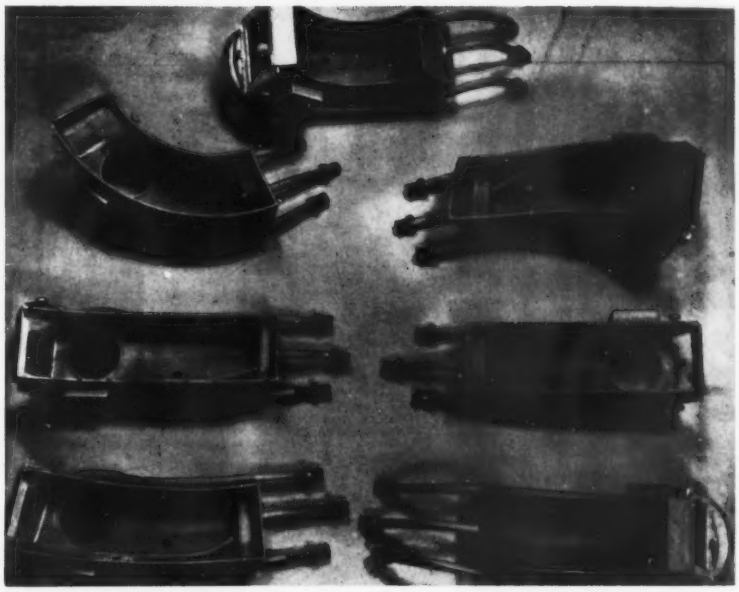


Fig. 3.—Portable shields for use on large weldments

weld metal as welding progresses. Joints can often be so designed as to avoid filler rod. For instance, instead of a straight corner weld, requiring filler metal, the joint can be made as a modified thrown fillet weld by melting down the protruding edge to reinforce the corner.

When welding sheet thicker than 0.05 in., or when the use of filler metal is unavoidable, welding is best performed in an argon filled box such as that shown in Fig. 2. Access to the work is by rubber gloves, which are blanked off when evacuating the box before back-filling with argon. Evacuating followed by back-filling is preferred to purging as it is much more positive and incidentally results in considerable economy. For best results, the box is evacuated to a pressure of approximately 1μ of mercury by a diffusion pump backed with a rotary pump before filling

Fig. 5 shows a tantalum bayonet heater fabricated from tantalum sheet which is a good example of the use of welding in tantalum fabrication. Bayonet heaters such as these are used in the chemical and petroleum industry for concentrating sulphuric acid and other corrosive media.

Table I gives figures which will be a practical guide to welding some of the reactive metals. They apply to straight butt welds made with no filler rod with the B.O.C. Mark III argon arc torch and jigged to provide protection to the back of the weld. Exact values of welding current will, of course, vary with the type of jig used.

Thinness a Problem

Tantalum and niobium, being rather expensive metals, are often used as thin sheet and this may cause trouble since it is difficult to weld thicknesses less than about 0.015 in. by the argon arc process unless special precautions are taken to stabilize the welding current and to jig the work to avoid distortion. However, resistance welding is very satisfactory for these thicknesses.

Welding is usually done under water, not because this affords protection in the usual sense, but because it quenches the weld and thus prevents contamination. Fig. 6 shows a typical set-up for welding under water. Apart from the water troughs, the equipment is quite conventional and either the transformer or stored energy type of equipment can be used. However, the welding head should be of the low inertia

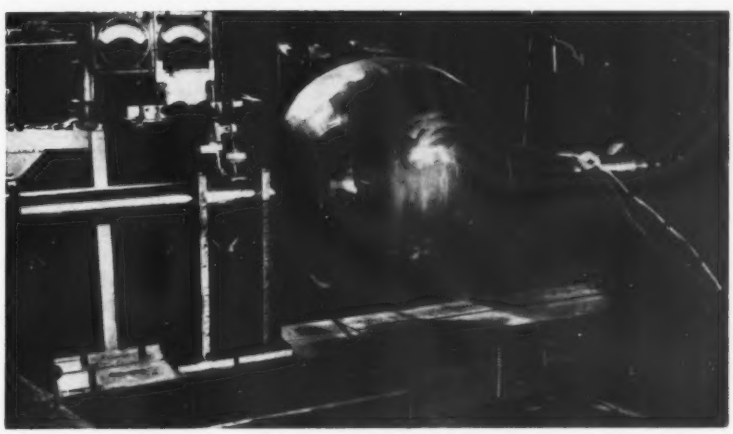


Fig. 4.—Zirconium core vessel for homogeneous test reactor

type so that as the welds are made, proper pressure is maintained during the welding cycle. Some data for resistance welding tantalum and niobium is given in Table II. The surfaces to be welded should be cleaned and degreased with acetone, carbon tetrachloride or trichloretholene.

To Avoid Copper

A common fault when resistance welding is to apply such a pressure to the joint that the contact resistance is lowered to the point where no weld occurs. Copper is often picked up on the welds from the electrodes, but this can be removed by pickling in dilute nitric acid. If removal is likely to be difficult, tungsten or tungsten-faced electrodes can be used.

There is no quantitative information on the resistance welding of zirconium but it has been stated[4] that a good starting point for the development of a welding procedure for any shape would be the welding data available for austenitic stainless steels.

Under the title " Vacuum Welding of Metals," J. A. Stohr and J. Briola[5] presented the first paper on this technique at the Technical Symposium on Fuel Elements held in Paris in November, 1957. The principle of the method is to accelerate and focus a beam of electrons on to the workpiece, moving the workpiece under the focal spot in order to obtain a continuous weld. The electron gun must operate in vacuum and this results in some very definite advantages for welding reactive metals, particularly with regard to purity of the welding atmosphere.

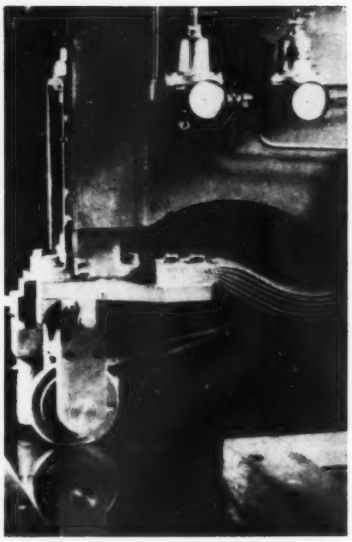


Fig. 6.—Resistance welding under water

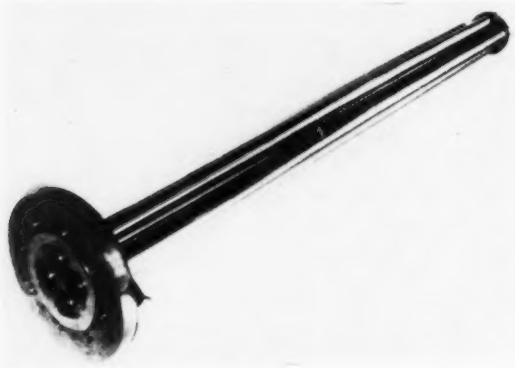


Fig. 5.—Bayonet heater fabricated in tantalum

This has always been a difficult problem when it was necessary to avoid contaminating the weld metal even by a few parts per million of oxygen or nitrogen—a requirement which arises for many nuclear energy applications—because of the difficulty of maintaining the purity of the inert gas in the welding chamber

TABLE I.—ARGON-ARC WELDING DATA. DIRECT CURRENT, ELECTRODE NEGATIVE

	Sheet thickness (in.)	Filler rod (in.)	Tungsten electrode diameter (in.)	Argon shield nozzle diameter (in.)	Argon flow		Welding current (amp)	Welding speed (in./min)	Remarks
					Torch (cu.ft/hr)	Back-up (cu.ft/hr)			
Tantalum	0.012	—	1/16	3/8	12	5	45	20	Machine weld
	0.020	—	1/16	3/8	14	5	80	25	" "
	0.030	—	1/16	3/8	14	5	100	25	" "
	0.030	—	1/16	3/8	14	5	80	—	Hand weld
	0.040	—	3/32	1/2	16	5	125	20	Machine weld
	0.050	—	3/32	1/2	16	5	150	20	" "
	0.060	—	1/8	5/8	16	5	160	20	" "
	0.060	—	1/8	5/8	16	5	120	—	Hand weld
	0.080	—	1/8	5/8	16	5	180	20	Machine weld
Niobium	0.012	—	1/16	3/8	12	5	40	20	Machine weld
	0.020	—	1/16	3/8	14	5	60	20	" "
	0.030	—	1/16	3/8	14	5	80	20	" "
Zirconium	0.020	—	1/16	3/8	14	5	40	50	Machine weld
	0.030	—	1/16	3/8	14	5	45	—	Hand weld
	0.040	—	3/32	1/2	14	5	60	25	Machine weld
	0.060	—	1/8	1/2	16	5	55	—	Hand weld
	0.060	—	1/8	1/2	16	5	80	25	Machine weld
	0.060	0.050	1/8	5/8	16	5	50	—	Hand weld
	0.090	0.080	1/8	5/8	16	5	60	—	" "
	0.120	0.080	1/8	5/8	16	5	94	—	" "
	0.150	0.080	3/16	5/8	16	5	140	—	" "
	0.185	0.080	3/16	5/8	16	5	165	—	" "

TABLE II.—SEAM WELDING DATA

	Sheet thickness (in.)	Tip load (lb)	Electrode wheel face (in.)	Weld speed (in./min)	Weld cycles		Open circuit voltage	Closed circuit voltage	Weld current (amp)
					On	Off			
Tantalum	0.020	50	0.10	36	2	2	2.7	0.7	4,500
	0.015	50	0.10	36	2	2	2.7	0.6	3,400
	0.010	50	0.10	36	2	2	2.7	0.5	2,800
	0.005	25	0.10	36	2	2	2.6	0.5	2,500
Niobium	0.020	50	$\frac{1}{8}$	36	3	2	1.6	1.25	4,000
	0.010	50	$\frac{1}{8}$	36	3	2	1.3	1.05	3,300
	0.005	25	$\frac{1}{8}$	36	3	2	0.8	0.7	1,100

and of avoiding contamination by water vapour adsorbed on the walls of the chamber. It is interesting to note that a vacuum of 5×10^{-4}mm is equivalent in this respect to a gas purity of 99.999987 as compared with normal welding gas of, say, 99.98-99.99 per cent.[6]

Some examples of weldments made by this technique are shown in Fig. 7, the beryllium welds being of particular interest in view of the difficulties which are experienced with cracking when attempting to weld by the argon arc technique. Fig. 8 shows a zirconium tank fabricated by welding with this new technique.

Problem Metal

So far, attempts to weld molybdenum have not been very successful. In common with all metals such as iron, having the body centred cubic type of structure, molybdenum shows a ductile to brittle transition temperature which varies with the state of work of the material, but which in fully recrystallized material can be as high as 300°C. Therefore weld metal in molybdenum welded by conventional means is almost always brittle. However, in very pure material the transition temperature is much lower. The electron beam welding method does offer the possibility of purification during welding with consequent ductility in the weld bead at room temperature. Of course, the heat-affected zone immediately adjacent to the weld metal will also recrystallize but it may be possible to avoid embrittlement by appropriate treatment.

Some preliminary tests have been carried out by M. E. Harper of Edwards High Vacuum, Ltd.[7] Simple bend tests on specimens ranging in thickness from 0.005 in. to 0.02 in. showed that some were sufficiently ductile to enable them to be bent 90° over a radius of about $\frac{1}{8}$ in., and where fracture occurred it was usually initiated in the heat affected zone.

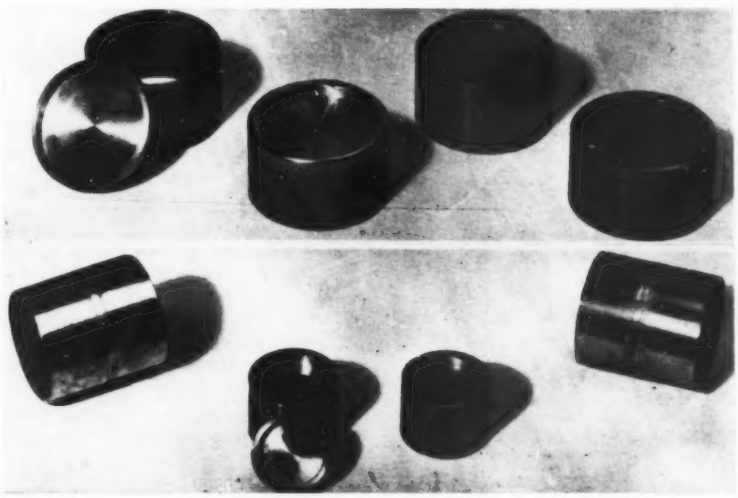


Fig. 7.—Examples of electron beam welds in zirconium (*top left*), uranium (*top right*) and beryllium (*bottom*)

The principle of cold pressure welding is based on the fact that if two metal surfaces are brought together by the application of external pressure and are deformed in such a way that, due to a difference in the ductility of the metal and its oxide film, the two metal surfaces make intimate contact, then a metallurgical bond is produced. At first sight this would seem an ideal way of welding reactive metals, but in practice its usefulness is severely restricted by the amount of deformation which is required to produce a sound joint—usually of the order of 50 per cent. or more.

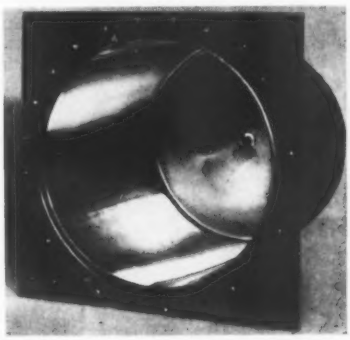


Fig. 8.—Zirconium tank fabricated by electron beam welding

Ultrasonic Process

The ultrasonic process is reported[8] to have been successfully used on titanium, zirconium, tantalum and other similar metals, but no details are given. The metals to be joined are clamped at low static pressure between welding tips (or sonotrodes as they are called) and ultrasonic energy is introduced for a brief interval, usually 1-3 seconds. A strong metallurgical bond is produced without external deformation

(which is the principle disadvantage of the cold pressure welding process). The principle of the process is shown diagrammatically in Fig. 10. The likely advantages are the fact that the material is only heated slightly, if at all, and the question of contamination does not arise. Similarly it should be possible to weld molybdenum without embrittlement.

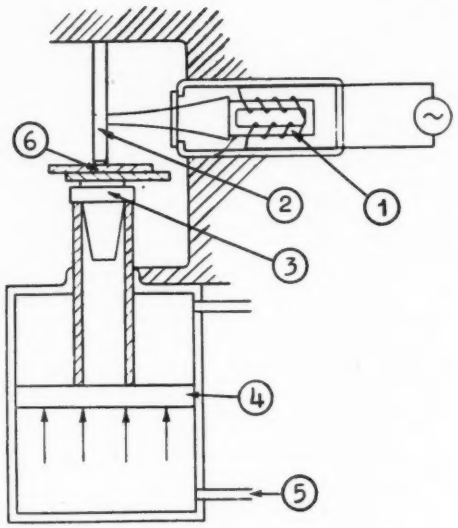


Fig. 10.—Principle of ultrasonic welding

Key:—1 Transducer in cooling tank, 2 Vibrating jaw, 3 Thrust pad, 4 Piston, 5 Compressed air, 6 Work.

Conclusion

In conclusion it may be said that for general fabrication purposes the argon arc process and the conventional electrical resistance technique are most useful. In special cases, however, the newer methods mentioned will no doubt be worthy of further development. For instance, in the nuclear energy field, where remote controlled welding equipment is required for sealing fuel element cans, it would appear that the electron beam welding technique will be ideal.

The Editor acknowledges the loan of Figs. 2, 3 and 4 from the publishers of "Welding and Metal Fabrication" and of Figs. 7 and 8 from Publications de la Soudure Autogene, Paris.

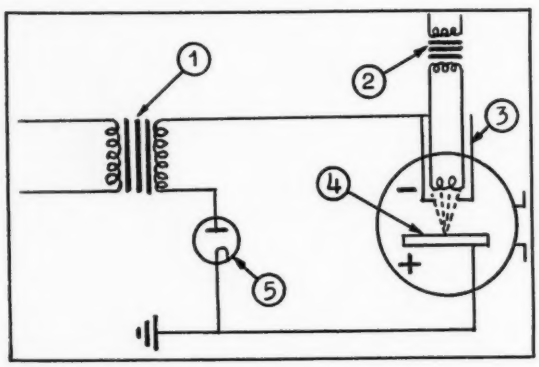


Fig. 9.—Principle of electron beam welding

Key:—1 E. H. T. Transformer, 2 Filament transformer, 3 Focussing points, 4 Travelling worktable, 5 Rectifier.

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WELDING AT HUNTERSTON

A COMPLETE automatic welding installation supplied by Quasi-Arc, Ltd., is now in operation on site at Hunterston nuclear power station. The design of this installation has presented numerous problems, and special machines have been produced to meet these exacting requirements.

Basically, the workshop area is divided into two bays, each serviced by an overhead 40-ton Goliath crane. Among the operations carried out in the first are the setting-up and tack-welding of the strakes that make up the boilers and the top and bottom heads. The strakes are then moved to the second bay which has two parallel sets of rails running down its length. It is in this bay that the main automatic welding operations are performed.

The longitudinal seams in the strakes are first welded with a traversing and swivelling welding boom, the largest of its kind in the world, each strake being supported on one of the 40-ton roller-beds. The strake then passes via turntables to the next set of rails for circumferential welding. For this purpose, a second and somewhat smaller traversing welding boom is used, running on a separate track alongside the roller-bed track. At the same time the swivelling boom, which runs on the first set of roller-bed tracks, can be turned through 90° and also brought into use over the second set of rails.

As the cylindrical vessel is built up it is X-rayed at every stage, holes are machined and nozzles and branches fitted; the complete shell is stress-relieved and hydrostatically tested, and finally the assembly is treated in a clean conditions chamber and dry-sealed ready for erection.

All welding is carried out by the Unionmelt process, using a total of four Quasi-Arc multi-power D.S.H. welding heads, mounted on two traversing raise-lower booms, two heads to a boom. In this method of welding two wires are used, each operating independently, having its own power source, feed motor, voltage control and nozzle assembly. Both wires are fed into a common weld pool. The current and arc voltage can be adjusted separately for each wire, allowing great flexibility in adjusting weld shape and penetration to obtain the best results at maximum welding speeds.

Both booms traverse on rails, having a welding speed traverse controllable between 6 in./min and 60 in./min, and a high-speed traverse of 20 ft/min for rapid positioning. Welding controls are provided at the welding head itself, governing all functions of both the boom and the traversing roller-beds supporting the section being welded. The operator is accommodated either sitting or prone at the welding head, and each boom carries its own power unit.

WELDING—Special Feature

ALUMINIUM and its Alloys

THEIR USE IN WELDED FABRICATIONS FOR NUCLEAR ENGINEERING

by W. A. Gardner, BSc, ARSM,
Aluminium Laboratories Ltd.
and
D. H. G. Abel, AMIMechE,
Northern Aluminium Co. Ltd.

Designers of nuclear engineering plant and equipment are being attracted to an increasing extent by the particular combination of properties offered by aluminium and its alloys. This article gives details of the properties of the most suitable alloys for fabrications in the nuclear engineering field. Brief consideration is also given to recent modifications of the argon-shrouded welding processes which make them more efficient for this type of high-quality work. Welding problems still being met in practice are discussed, and it is suggested that solutions can often be found from a knowledge of the basic weldability of the available alloys. The article also describes some applications in the nuclear field, brief details being given about the joining and fabrication techniques used

ALUMINIUM and its alloys are commonly available as sheet, plate, extrusions, rolled bar and rod, tube, wire, forgings and castings. As extracted from the ore, aluminium is of " commercial " purity, containing about ½ per cent. impurities, mainly iron and silicon, and in this form is soft and ductile at normal and sub-zero temperatures.

Alloys have been developed to possess in the manufactured condition the best combinations of properties for particular purposes, the principal alloying elements being copper, magnesium, silicon, manganese, zinc, nickel and chromium. Other elements that are sometimes used in special alloys include beryllium, cadmium, cerium, columbium, lead, tin and titanium.

Only a Few Used

An extensive range of alloys is now available. In general, however, only a few, in the form of high-purity (B.S.1470-1477:S1) and commercial-purity aluminium (S1A, S1B and S1C), aluminium-manganese (N3), aluminium-magnesium (N4, N5/6 and N6) and aluminium-magnesium-silicon alloys (H9, H10 and H30) are used in nuclear power schemes.

Of the engineering metals, only three—magnesium, beryllium and zirconium—have lower neutron-absorption cross-sections than aluminium, and this fact, coupled with its ease of fabrication, made aluminium a natural choice for early thermal reactors, particularly as a canning material. Addition of certain alloying elements such as copper, manganese and nickel, however, affect its neutron economy.

Lightweight

With a specific gravity varying between 2.5 and 2.8 g/cu.cm, compared with 8.9 for copper and 7.9 for steel, aluminium is one of the lightest metals. This is a considerable advantage where transport and handling are involved.

The natural oxide film on the surface of aluminium, which reforms immediately on damage (provided that oxygen is available for this purpose) renders the metal highly resistant to corrosive attack by a large range of chemicals and chemical atmospheres. The surfaces of those alloys whose corrosion-resistance is lower are often protected by coating with purer aluminium. An example of this is in clad tubing, which is produced for use with natural and untreated waters, including sea water, and is now being extensively applied in the construction of heat exchangers and similar plant.

At temperatures below 100°C., aluminium is generally resistant to attack by pure water (although some alloys are less so than others), but at higher temperatures, and particularly above 200°C., even high-purity metal is liable to inter-crystalline corrosion. This can be reduced to a considerable extent by the addition of such alloying elements as nickel, iron and titanium.

Aluminium, magnesium, stainless steel and zirconium all possess an oxidation-resistance which is adequate to permit their use in carbon-dioxide-cooled reactors operating at 400°C.

This immunity of aluminium and many of its alloys from chemical action, together with its low half-life, could be an advantage in that aluminium canned food is usable a very short time after irradiation.

More Advantages

Pure aluminium is highly conductive to heat and electricity, being second only to copper among the industrial metals. Its electrical resistivity is 2.8264 michrohm/cm, and for equal temperature rise, an

aluminium conductor has a current-carrying capacity of 80 per cent. of a copper conductor of the same size. Again, alloying and impurities reduce the conductivity slightly, but by comparison with iron and steel the values still remain high.

Aluminium and its alloys are also non-magnetic, which is an advantage if they are used in applications located near delicate instruments.

Bright aluminium surfaces reflect about 85 per cent. of the light and about 90 per cent. of heat radiation that fall upon them: thus, although it is an ideal thermal conductor, aluminium is also a useful heat insulator and is frequently used for this purpose, usually in the form of foil. The coefficient of thermal expansion is high, being about twice that of steel and one and a half times that of uranium; this is an important consideration where problems of differential expansion are likely to be encountered.

When Variations Occur

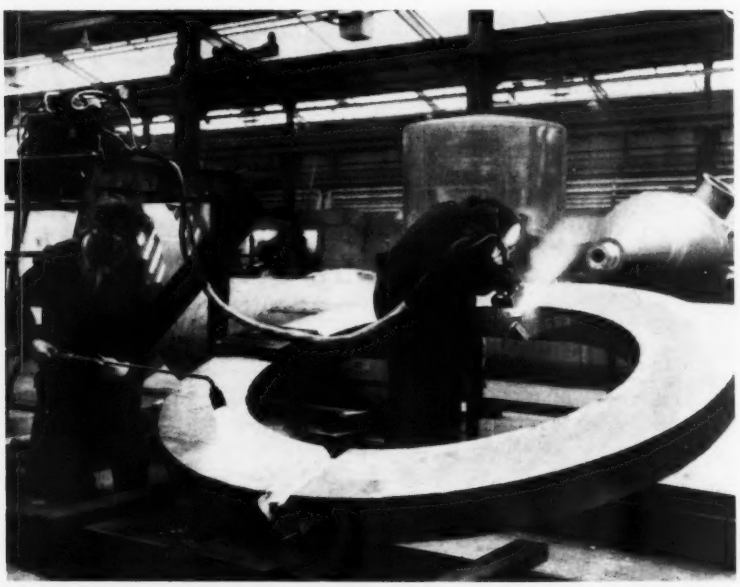
The mechanical properties of aluminium and its alloys vary with their chemical composition, form, and degree of cold working or heat treatment received. A summary of these properties for the commoner commercial alloys is given in Table 1. At elevated temperatures the strength of both work-hardened and heat-treated alloys decreases, with a corresponding increase in ductility. At sub-zero temperatures the alloys under consideration show some increase in tensile properties and elongation values. In contrast with steel, no tendency to brittle fracture is evident at low temperatures. The modulus of elasticity for aluminium and its alloys ranges between 9.5 and 10.5×10^6 lb/sq.in., torsion modulus between 3.5 and 3.9×10^6 lb/sq.in., and Poisson's ratio between 0.32 and 0.34. Shear strength, for design purposes, is usually taken as 60 per cent. of the tensile strength.

Based on 50×10^6 cycles, the fatigue strength of laboratory specimens of the work-hardened alloys varies between 3.5 and 9 ton/sq.in.

Much work has been undertaken by McKeown, Eborall, Lushey, Servi, Grant, Simmons and Cross among others on the creep characteristics of aluminium, and this has been summarized elsewhere. In general it has been found that creep takes place at measurable rates at fairly low temperatures and stresses. Tests on 99.8 per cent. aluminium, for instance, show that after 5,000 hours at 20°C., 50°C. and 80°C., and stresses of 3,000, 1,600 and 600 lb/sq.in. respectively, creep was of the order of 0.5×10^{-7} in./in./hr.

Above 250°C., high-purity coarse-grained material is slightly more resistant to creep than medium-grained material, but in any case the creep rate is then considerable at comparatively low stresses. Such factors as grain size, heat treatment, structural stability, and chemical composition all have considerable influence on the creep characteristics of aluminium alloys although evidence of the effect of each is rather inconclusive. Probably the best alloys from the creep aspect are those containing substantial quantities of nickel, such as the casting alloys LM13 and 14, and the forging alloys DTD.717, 724, 731 and BS5L25. Alloys H15 and DTD.683 are also worthy of consideration.

A noteworthy application of aluminium was the ZETA torus, part of which is shown here during its construction at the works of Metropolitan-Vickers Electrical Co., Ltd. The torus has a bore of 3½ ft and a maximum diameter of about 11 ft and was fabricated in 1 in. thick commercially pure aluminium plate from 28 short cylinders with angle ends. The choice of alloy and welding process was governed by the requirements of a low uniform electrical resistance of the finished torus consistent with a straightforward method of fabrication



The inert gas welding of a 99.5 per cent. purity aluminium ring, from which a butt welded flange is subsequently machined, is shown here. This component is part of a swimming pool reactor being fabricated at the works of A.P.V., Ltd. Local pre-heating was necessary and was controlled closely by means of temperature-indicating crayons to ensure accurate weld shrinkage values

Weldabilities

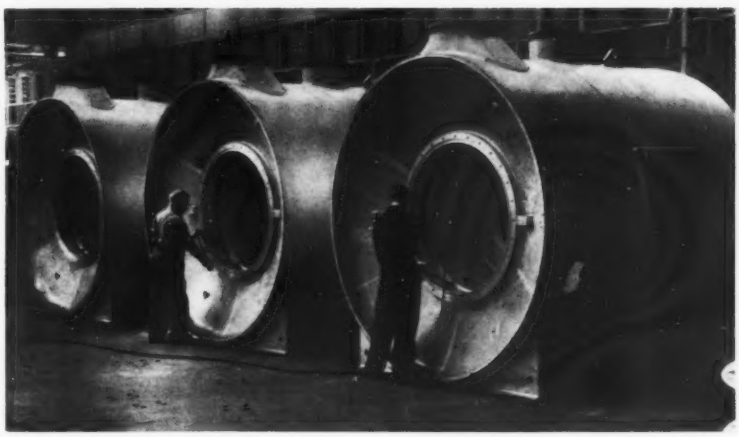
Almost all the common aluminium alloys are now weldable but their respective weldabilities vary, particularly with regard to hot cracking

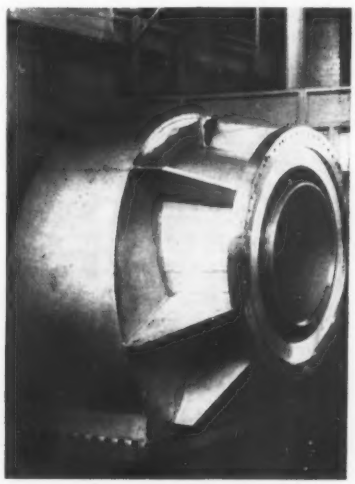
TABLE 1.—Specified Mechanical Properties of some Wrought Materials

Material designation	Condition	0.1 per cent. proof stress, ton/sq.in.	Tensile strength (minimum unless a range is given), ton/sq.in.	Elongation on 2 in. (minimum) (material thicker than 12 s.w.g.), per cent.	Bend radius (minimum) (material 12 s.w.g. and thinner), t = thickness
S1B	O	—	6.0 (maximum)	30	Flat
	¼H	—	6.5–8.0	8	½t
	H	—	8.5	5	1t
P1B	M	—	4.0	30	—
	½H	—	6.5–8.0	8	—
NS3	O	—	7.5 (maximum)	30	Flat
	¼H	—	7.5– 9.5	12	Flat
	½H	—	9.0–11.0	7	½t
	¾H	—	10.5–12.5	5	1t
	H	—	11.5	3	3t
NS4	O	—	11.0–14.0	18	Flat
	¼H	9.0	13.0	8	½t
	½H	12.0	15.0	5	1t
NP4	M	—	12.0	12	—
NS5	O	6.0	14.0	18	Flat
	¼H	11.0	17.0	8	1t
NS6	O	8.0	17.0	18	Flat
	¼H	14.0	19.0	8	2t
NP5/6	M	8.0	17.0	12	—
	O	7.0	17.0	18	—
HS3O	O	—	11.0 (maximum)	18	Flat
	WP	7.0	13.0	15	2t
	WP	16.0	19.0	8	3t
HP30	W	7.0	13.0	15, 12	—
	WP	15.0	19.0	8, 6	—

and porosity tendencies. A considerable amount of work has been done on these problems by a research team sponsored by the Aluminium Development Association, and also by the British Welding Research Association, which has shown that both these troubles can be attributed to the adverse metallurgical characteristics of compositions approximating to those of maximum solid solubility.

They have also established that such compositions should be avoided in the alloy which is formed locally by dilution of the filler metal by parent metal fused into the weld bead. In particular, it appears that maximum cracking and porosity compositions for the Al/Mg alloys





Aluminium vessels fabricated by the Fairey Aviation Co., Ltd. Those on the left weigh four tons apiece and the one above about two tons. The alloys NP 3 and NP 5/6 were chosen for these fabrications because of their compatibility with the products being processed. Welding throughout was by the inert-gas-metal-arc process, to the vacuum test standards of the UKAEA

are in the range 1.5 to 2.5 per cent. Mg, while for the Al/Si series the equivalent range is 0.5 to 1.5 per cent. Si. It therefore behoves designers and welding engineers, by prior consultation, to avoid choosing alloys and filler compositions that are likely to result in weld beads in these composition ranges.

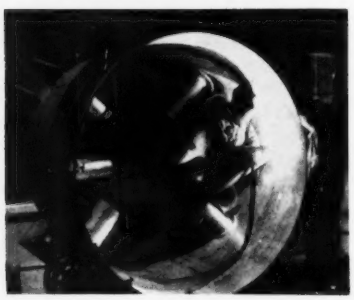
Prone Alloys

It is realized, of course, that considerations in nuclear engineering do not always make this possible. Assemblies particularly prone to cracking and porosity, but often specified, are:—N3 alloy welded to N4 alloy with N6 filler, N4 welded to itself with a filler containing less than 5 per cent. Mg (and even with this filler in high-dilution welds) and H10 or H30 alloys to N4 with N6 filler.

The characteristics of the argon-tungsten arc and inert-gas-metal-arc welding processes make them ideally suited for fabrications of the high-quality for which the atomic energy

Inert-gas-metal-arc welding being carried out on the interior of a Merlin reactor core tank for Western Germany. The tank body was built by A.P.V., Ltd., of 99.5 per cent. purity aluminium and the facility tubes in 99.8 per cent. purity metal

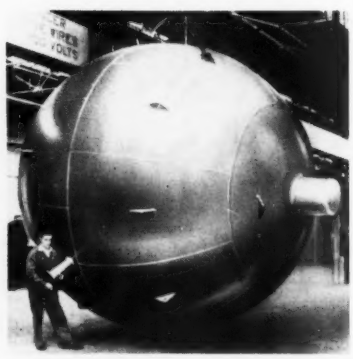
Dual-operator argon-tungsten arc welding on an aluminium reactor core tank is shown below. The two operators work vertically upwards, one adding filler wire and the other controlling penetration



industry so rightly calls. The salient features of these processes are well known, and consideration will only be given here to recent equipment advances.

Recently-marketed argon-tungsten-arc equipment incorporates a change in the method of stabilization. This advance has been made possible by fundamental work carried out by the Electrical Research Association, and utilizes for arc stabilization a high-voltage surge phased at the null points of current and voltage in the a.c. supply. The system enables lower open-circuit voltage transformers to be used, results in less radio and television interference and, by imparting smoother arc characteristics, has led to easier control and an improvement in weld quality. Following improvements in powder metallurgy techniques, the currently-available tungsten electrodes incorporate higher percentages of thoria and zirconia. The higher electron emissivity of these new electrodes prevents them from becoming overheated in use, and consequently reduces the danger of tungsten inclusions in the welds.

In the inert-gas-metal-arc welding field the commercial availability of rectifiers with sensibly flat volt/ampere characteristics has led to increased self-adjustment of arc length and voltage, with beneficial effects on weld quality. The introduction into this country from America of inert-gas-metal-arc welding equipment with vastly improved electrode wire feeding characteristics is also expected in the near future.



A spherical surge vessel, 14 ft in diameter, fabricated by Marston Excelsior, Ltd., from pressed aluminium segments $\frac{3}{4}$ in. thick to tolerances in accordance with BS.1500

Better Welding?

Such equipment, by incorporating the wire feed rolls on the gun itself, allows electrode wires down to 0.020 in. diameter to be used. Not only will this new equipment enable $^{1}/_{16}$ in. thick aluminium to be welded by the faster and more economic I.M.A. process but, because of the more efficient electrode feed, an improvement in weld quality is expected.

Also of interest to the nuclear engineer is the introduction of the tungsten-arc cutting process for aluminium, which fills a long-felt want. The finish of the cut edge is suitable

for welding without subsequent machining, and is likely therefore to reduce markedly the cost of edge-preparing thick plate.

In the hands of a fully experienced operator, the argon-tungsten-arc process poses no outstanding problems. Fabricators have now built up a fund of experience, and the late-comers in the field will be greatly assisted when a British Standard on recommended procedures for argon-tungsten-arc welding of aluminium is published in the near future. Tungsten inclusions, although not attributable to equipment deficiencies, are still experienced, but are commonly the result of using too small an electrode.

Porosity Problem

The fundamentals of the inert-gas-metal-arc welding process are still being actively investigated, but it is now appreciated that sound welds can be produced only if a minimum and maximum current density range is observed for each electrode diameter and composition. The one outstanding problem with the process is weld porosity. Improvements in this respect have been reported by the use of argon-helium shrouding gas mixtures (in this country of academic interest only, because of the lack of helium) and by the introduction of small amounts of chlorine into the welding arc.

TABLE 2.—Typical Strengths of Joints made by Inert Metal Arc Welding

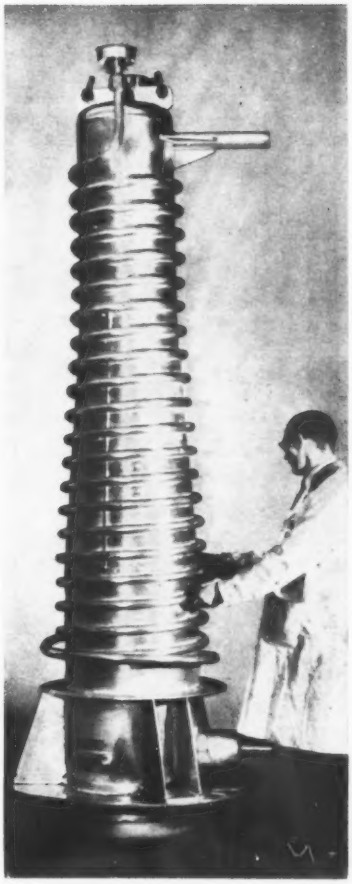
Material B.S.S.	Butt welds, typical ultimate tensile stress (ton/sq.in.)	Longitudinal fillet welds, typical ultimate shear stress (ton/sq.in.)
1C	5½	3
N3	7	4
H20WP	12	8
H30WP	12	8
N4	11	6
N5/6M	17	9
N6M	17	9

Cleanliness Factor

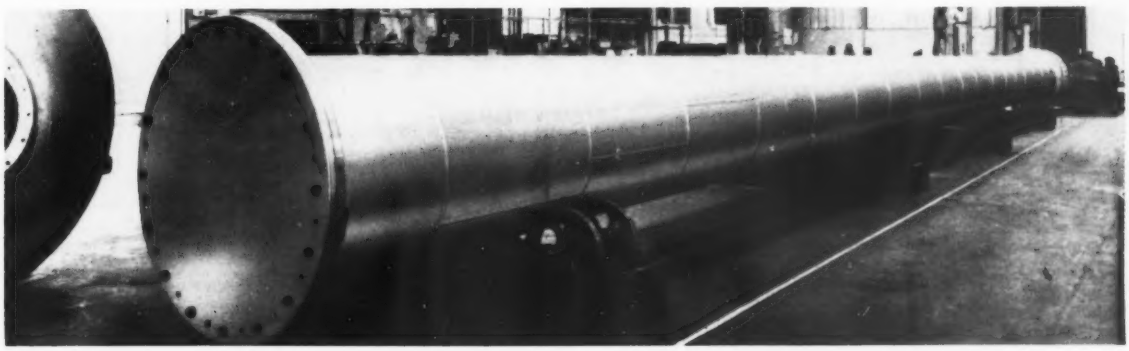
Unfortunately, the use of chlorine causes corrosion of the welding equipment, a problem that requires solution before the technique can be applied commercially. It is quite wrong to assume, however, that porosity is inherent in this process, since a correct and reproducible choice of welding variables and an experienced operator can consistently satisfy even the highest X-ray requirements. In this respect one of the most important and least appreciated factors is arc voltage.

Also, the necessity for weld cleanliness cannot be over-emphasized for high-quality work. Old or contaminated electrode wire is also a frequent cause of porosity, and the stringent cleanliness standards observed in manufacture of this product can often be nullified by poor storage and failure to use stocks quickly enough. The attention of fabricators is particularly drawn to this point.

It is fortunate that the initial growth of the nuclear engineering industry has taken place at a time when techniques of welding aluminium and its alloys have been greatly improved. These new methods have not only enabled designers to use the light metal to an extent that would not have been practicable a few years ago, but will encourage nuclear engineers to take even fuller advantage of aluminium's versatility as the industry expands.



The corrosion resistance and thermal properties of aluminium condensers and heat exchangers are increasingly being recognized in the nuclear field. An outstanding example is shown above. Made by Marston Excelsior, Ltd., it is fabricated from ⅜ in. thick N3 plate and the coil of 1 in., 99.5 per cent. aluminium purity tube. The 77 ft long section illustrated below is part of a 300 ft long aluminium linear accelerator fabricated by the same firm. This unit when assembled has an out-of-straightness tolerance of ½ in. and the tube, which is 41 in. in diameter, is round to within ±1/16 in. The material used was NP5/6



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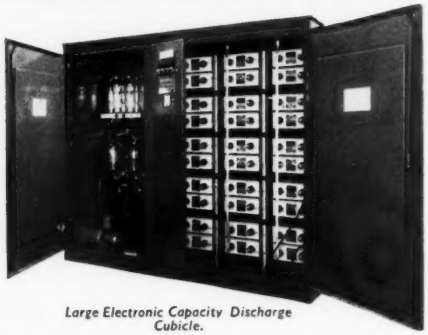

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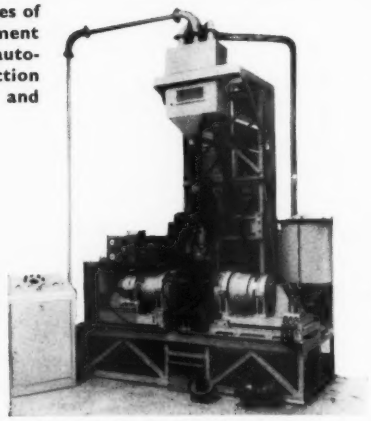

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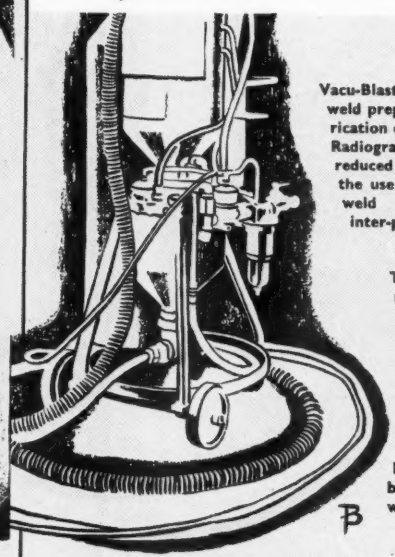

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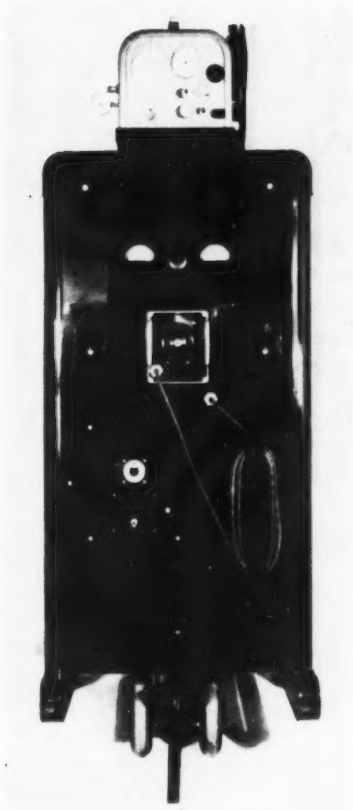
Welding Equipment and Processes

Items published in this special feature are compiled from manufacturers' current literature. Readers requiring further information should use the form at bottom of the page.

No Flux Needed

Among nuclear projects in which welding has been undertaken with equipment and processes of British Oxygen Gases Ltd., have been the building of the Dounreay fast breeder and materials testing reactors, the construction of thermonuclear toroidal assemblies at Harwell, including ZETA, and, currently, CEGB power station projects. Latest welding apparatus made available by this firm includes the Lynx welding equipment which enables welds to be made at currents of up to 600 amps, at high speeds and without the aid of flux, in aluminium and its alloys, copper and its alloys, and corrosion resisting and mild steels. The equipment is designed for consumable electrode gas shielded arc welding. In this a consumable bare wire is fed into the weld at constant speed whilst a continuous blanket of gas shields the weld zone from atmospheric conditions. The equipment comprises four main items:—the carriage unit, the relay unit, the welding gun, and the power source. The carriage unit embodies an enclosed spindle assembly for the wire reel, feed rolls and wire feed motor. The latter is fitted with an electro mechanical governor which gives a wire speed range of 60 to 600 in./min. Total weight of the unit is 40 lb; the spindle assembly and reel can be readily disconnected to form two separate portable units. A choice of two welding guns is available, the guns being interchangeable without modification to the equipment. The air-cooled gun is intended for use where current requirements are under 300 amps, as for example for aluminium and its alloys. The water-cooled gun is for use at currents of up to 600 amps. A special failure device that trips out the welding current if the water supply fails is fitted. The relay unit houses specially designed relays which control the services to the welding gun. Features include connectors designed to prevent different services being coupled incorrectly and interchangeable relays to facilitate testing and servicing. Power for the equipment can be supplied from any d.c. rectifier or generator, though rectifiers specially designed for it are available. These are the MRL 425, consisting of a combined transformer and selenium plate metal rectifier and the CPR 400, which is a flat characteristic rectifier ideally suited for the welding of aluminium and its alloys. **(JN 1)**



Lynx carriage unit with MRL 425 rectifier as supplied by British Oxygen Gases Ltd.

Medium Machines

E.B.G. medium frequency welding generators supplied by Rediweld-Oerlikon are available in two sizes with outputs of 145 or 250 amps. They are intended for use in repair shop, factory or site, and the smaller set has been particularly well received by sheet metal workers. The units are similar in construction and consist of a single phase alternator mounted directly on the shaft of a three phase squirrel cage motor; the balanced input load is popular with electricity supply companies, and with a power factor rising above 0.9 at 90 per cent. load they are economical in use. The alternator is of the rotating pole wheel type, the poles consisting of permanent magnets thereby eliminating brush gear, rotating windings, etc. The welding current is taken direct from stationary windings. The dropping characteristic is inherent in the design, no additional chokes or resistances being employed; the output current is controlled by multi-position switches. The 250 amp set has an output frequency of 425 c/s while

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the 145 amp unit operates at 330 c/s. These frequencies permit the use of lower than average open circuit voltages and show marked improvement in the striking and maintenance of the arc compared with a 50 c/s transformer. Welding speeds are increased by up to 30 per cent. and welds are remarkably free from slag inclusion even under adverse conditions. Both sets are suitable for use with low hydrogen (lime-fluorspar) and stainless electrodes, and may be run in parallel if high outputs are required. A diesel powered version of the 250 amp set is also available or the alternator only can be supplied for coupling to the power take off of existing plant. **(JN 2)**

Automatic Unit

Among the pioneers of automatic arc welding in this country are the Lincoln Electric Co., Ltd., of Welwyn Garden City, Herts, and their automatic submerged arc welding heads are as widely used in the nuclear field as in any other industry. They claim to be the first company in the world to produce all types of fused and un-fused fluxes for the welding of mild steel to Class I requirements. They also supply a wide range of special fluxes and electrode wires for the submerged arc welding of 12 to 14 per cent. chromium stainless iron, 18/8 austentitic steels (including niobium and molybdenum bearing steels), and molybdenum bearing and chrome molybdenum creep resisting steels. The company's type B.10 fully automatic submerged arc welding head is a stationary unit which can be mounted on retractable column and boom suitable for the internal and external welding of vessels and pipes of all sizes, thicknesses and diameters. Both fillet and lap welds can be carried out with the unit, in addition to conventional "downhand." Other features of this unit include a guide light to enable the operator to follow the track of the wire, a polarity switch, dust proof easy to read meters, and immediate "contact starting." All sizes of wire can be used without changing gears or jaws. The B.10 can be made "Twin Arc" with the minimum of adjustment. Basically similar to this unit is the B.11, the chief difference between the two being that the B.11 head is mounted on a self-propelled travel carriage that moves along a fixed beam. The C.10 is also similar, but self-propelled. Two other Lincoln welding units are the M.L.2 and M.L.3 semi-automatic submerged arc welders. Though designed for welding by hand these units can be mounted on a carriage and turned into fully automatic units; unlike the M.L.2, the M.L.3 is provided with remote control enabling the operator to regulate current and voltage at the point of welding. **(JN 3)**

For Light Work

The selenium arc welding rectifier equipment made by Hackbridge and Hewittic Electrical Co., Ltd., of Walton-on-Thames, Surrey, is completely static and by transductor control enables smooth stepless on-load current control over the full range to be obtained. The transductor control is of a patented design having characteristics ideal for arc welding. A small standard equipment is made for a current range of 5-50 amps. d.c. from a 200-250v single phase 50 cycle supply and is for static floor mounting. If desired the unit can be provided with rubber-tyred castors and re-proportioned for mobile use. This size of equipment is intended for light welding such as for welding of sheet metals, including mild steel, stainless steel, aluminium and other non-ferrous metals suitable for arc welding. Equipments of larger capacities can be provided. They can also be arranged to be suitable for either a.c. or d.c. welding, under transductor control in each case, by switching the rectifier units in or out of circuit by a changeover switch. **(JN 4)**

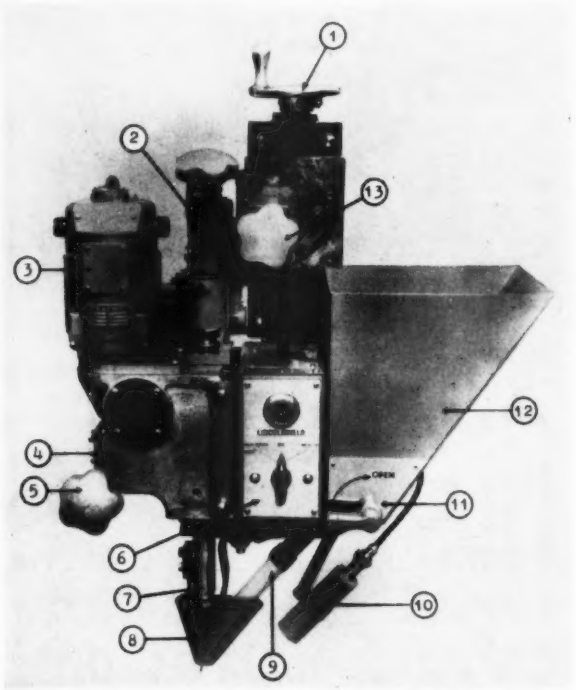
Portable Welder

The Actarc range of precision built welding rectifiers, made by the Arc Manufacturing Co., Ltd., are designed primarily for the inert gas welding of light gauge materials such as titanium and nimonic. The rectifiers are rated for continuous welding at a maximum current and a reliable performance is ensured over long periods with a minimum of maintenance. Complete control of all variables is arranged through a remote control unit which is operated either by push button or foot control. A development of this type of rectifier is one with a capacity of 40 amperes which was specifically designed for BOAC for carrying out maintenance work on aircraft in hangars. The latest addition to Arc Manufacturing Co's., range of welding transformers is the "Module," which has a capacity of 250 amps. It is portable and is capable of using up to 6 s.w.g. electrodes. It has a low mains intake with vacuum impregnated windings, and has two current ranges. There is a dual voltage range of 50v. and 80v. **(JN 5)**

Used in Glove Boxes

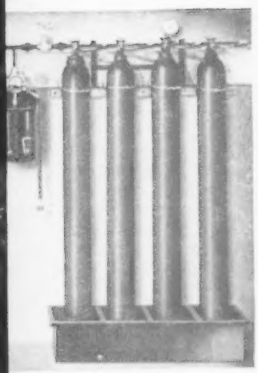
Originally developed for the industries where welding reliability is of paramount importance and where the demand for a welding machine capable of giving absolutely consistent performance is essential the Slee RK spot welders are now finding an application in nuclear engineering, where they have been incorporated in glove boxes, etc. With suitable associated control gear, they are capable of a reliability performance better than 1 in 10^7. Capacity and range of work that may be handled by this welder is extremely wide and versatile. Practically every known metal and alloy including uranium, silver, molybdenum, tungsten, carbon steel, copper, brass and aluminium is being welded with it. Wires of 0.0003 in. in diameter and sheet down to 0.0001 in. thick represent the type of delicate welds possible, while at the other end of the range the rating is such that $^3/_{16}$ in. diameter mild steel rods may be welded together. The South London Electrical Equipment Co., Ltd., also make a comprehensive range of over 40 standard types of plenum benches, pressurized, evacuated or sealed (glove box type)

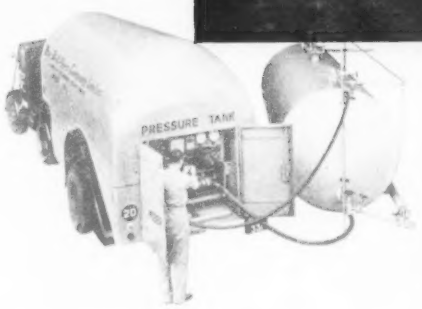
(*Continued on page* 55)



View of the Lincolnweld B 10 head showing the main operating controls. Key—1 Vertical slide adjustment, 2 wire straightner, 3 wire feed drive motor, 4 wire feed gear box, 5 cross seam adjustment, 6 control station, 7 nozzle assembly, 8 flux shroud, 9 flux feed tube, 10 guide light, 11 flux valve, 12 flux hopper, 13 cross slide adjustment

Photograph illustrating the FUSARC/CO_2 process by courtesy of Quasi-Arc Limited





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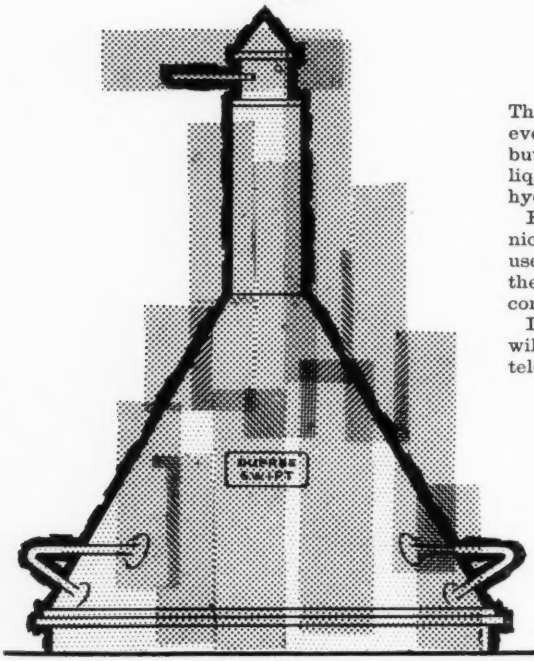

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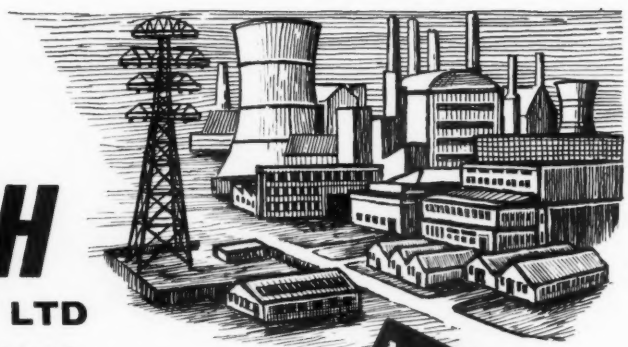

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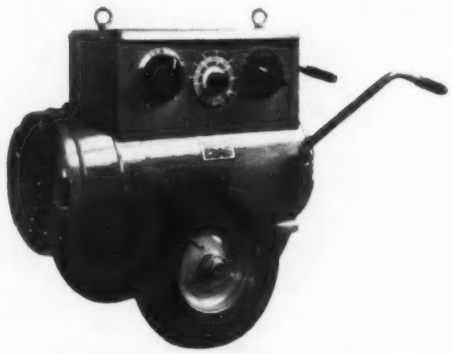
Used on CEGB Sites

Hand welding of the heat exchangers at Calder Hall and of the boilers for Berkeley was carried out with O.K. Unitrodes made by Welding Supplies Ltd., of Gillingham, Kent. These were also used for the hand welding of the Berkeley reactor casings, thermal shields and CO_2 ducting. Overall X-ray examination showed that less than one per cent. of the welds needed any repair. At Bradwell, an O.K. Tensitride 34 was used for the hand welding of all the nozzles and domed ends of the boilers, with similar results; d.c. welding current was selected for use on all these projects. At Berkeley 110 KB. 375 arc welding generators are in use and nearly 50 of these machines have been ordered for Hinkley Point. The KB.375 was designed to the combined requirements of some 2,000 welding engineers who completed questionnaires stating their ideas for the ideal welding generator. Features of this equipment include an externally mounted isolation switch, Star Delta or direct-on-line push button starters and thermal overload devices built into the motor windings, providing the KB.375 with about the most complete protection of any machine available. It will be appreciated that externally mounted overloads depend on increasing current demand to trip them, whereas in the KB.375 the actual temperature of the windings operates the trip, conversely, it is the windings which must cool before the machine can be restarted, premature starting being guarded against by means of the built-in overloads. The generator is available in four current ranges with generous overlaps, so enabling the most suitable characteristics for any particular application of the electrode to be selected. A stepless shunt field regulator controls the final adjustment between 20 and 400 amps. Throughout the range, arc recovery is almost instantaneous ensuring that true welding current is available immediately the electrode is restruck. Other equipment made by Welding Supplies Ltd., includes the O.K. Cadet "MH" oxygen cutting machine. Powered by a compact electric motor and mounted on magnetic driving wheels, this machine can cut steel plate between $\frac{3}{4}$ in. and 3 in. thick in any position. **(JN 7)**



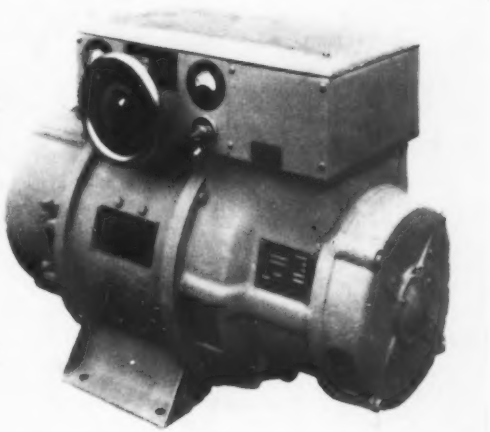
KB 375 arc welding generator as used at the CEGB nuclear power station sites. Manufacturers are Welding Supplies Ltd.

Stud Welding

What started 30 years ago as a primitive method of attaching small brass studs to ships' bulkheads in H.M. Dockyards, has now evolved into a well understood and accepted process designed to meet the needs of most branches of the metal working industries. Stud welding is used in the fabrication of every conceivable type of plant and equipment. Specialists in this type of welding are Crompton Parkinson Ltd. who make a full range of transformer rectifiers, controllers and welding heads. **(JN 8)**

Arc Welders

Standard electric arc welding equipment supplied by A. Reyrolle & Co., Ltd., of interest to nuclear engineers includes the S425A single operator welding set, the S174A set and the concentric dual control arc welder. The first two units have Holmes patented dropping characteristic d.c. generators giving approximately 70v on open circuit for striking arc. Current range of the S175A is 15-175 amps, of the S425A 70-425 amps, arc voltage output is 20-25 and 25-40, respectively and continuous welding current to B.S. 638:1935 125 amps and 300 amps, respectively. Motor speeds of the two units are 3,000 rev/min and 1,500 rev/min respectively. Both units can be supplied mounted on wheels for portability. The concentric dual control arc welder has a type-B dropping characteristic direct d.c. generator with a current range of 20-300 amps at 20-30 arc volts. Striking voltage is 70v and its rating 200 amps for continuous welding to B.S. 638 and 300 amps for intermittent welding. Current control is provided by means of a special concentric dual control, enabling different characteristics to be selected at will to suit various positions and conditions of welding. **(JN 9)**



Holmes arc welder as supplied by A. Reyrolle & Co., Ltd.

Surge Injection Basis

The new Saturn-Hivolt arc welding machines, Mk II and Mk III, offer users many advantages in both performance and simplicity of operation. They are designed for welding aluminium and its alloys and stainless steel and operate on the surge injection principle. They provide a complete argon arc welding set, immediate arc starting from cold without a carbon block, efficient plate cleaning, complete penetration, automatic control of gas, completely stable welding arc, production welding with direct or remote control, elimination of the danger of electric shock, a flexible arc which permits use of semi-skilled labour and continuous variable control of welding current. **(JN 10)**

Portable Rigs

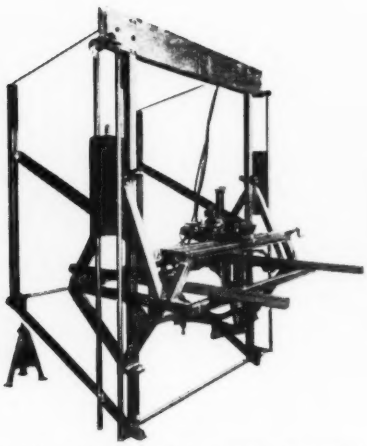
Reduced cost and greater output in the preparation of tubes for butt welding have been achieved at the Glasgow works of John Brown Land Boilers Ltd., by the use of portable rigs which are easily moved about the works. In this way machining can take place at any convenient location and the need for expensive horizontal boring and facing machines which would require the work to be brought to them

(*Continued on page* 57)

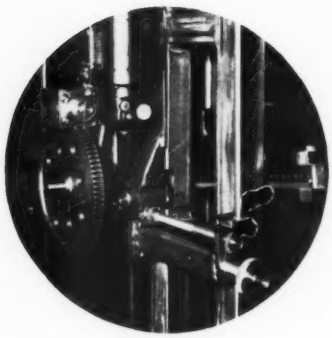
Special

OXYGEN CUTTING MACHINES

Burner Assembly



A machine manufactured for cutting the holes in steel reactor shells to receive charge tubes



Drive Unit

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PROFILE MACHINE AND PLATE CONVEYOR SPECIALISTS

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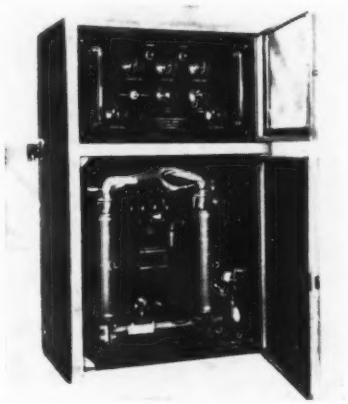
is eliminated. Each rig consists of a consolidated pneumatic type 350-R-100 heavy duty power vane drill mounted in line with two ball races and a vice on a common baseplate. The drill is fitted with a No. 5 morse taper spindle which is held rigidly by the ball races spaced 5½ in. apart. A specially designed cutter head carrying two Cleveland twist drill cutters of 10 per cent. cobalt steel is mounted on the spindle, the head carrying recesses for cutting teeth suitable for dealing with tubes in the size range of 1½ in. O.D. to 6 in. O.D. and thicknesses of from 10 gauge up to ½ in. A particular feature of the assembly is that whilst the rig allows of working to within limits of .005 in. only semi-skilled labour is required for its operation and head change is accomplished in a matter of seconds by the operators. The consolidated pneumatic type 350-R-100 air drill is a standard reversible model and has a spindle speed when running light of 100 rev/min. It has an overall length of 22⅜ in. and a weight of 85¾ lb. The standard drill is fitted with feed screw, safety live air throttle and dead handle. **(JN 11)**

Control Equipment

Welding controller I.C.T.11, made by W. H. Sanders (Electronics) Ltd., of Stevenage, Herts, consists of an ignitron contactor controlled by a synchronous electronic timer unit. The contactor will accommodate either "A" size or "C" size ignitrons. Developed primarily to provide



Welding controller, model IC 11, made by W. H. Sanders (Electronics) Ltd.

a precision welding controller at a cost of little more than a non-synchronous type, this controller has applications in a wide range of welding processes. Features of the timer unit, type W.T.16, include means of calibrating and independently adjusting the weld and forge, an independent variable repetition rate control, heat control, a selector switch for single shot or repetitive operation, independent timing sequences, safety in the event of component failure, ease of servicing and reliability under conditions of vibration and shock. The sequence of operation of the controller is as follows:—When the initiation switch is closed the welding head of the machine is lowered by the air valve which is operated by a relay or valve in the timer. The start of the " Weld Time " is controlled in one of two ways. (*a*) Squeeze time: A time preset to hold off the welding current until the electrodes are closed with sufficient pressure on the workpiece. (*b*) Pressure switch: A switch operated by the back pressure set up when the electrodes are tightly clamped on the workpiece. Having obtained the required electrode pressure on the workpiece welding current will flow for a preselected number of cycles and " Forge Time " will then commence. During " Forge Time " the electrodes are held together on the workpicce consolidating the weld. Should the controls be set to " Single " the sequence is now completed and the head will open and remain in that position unless re-initiated. With the control set to " Repeat " the head will rise for selected " Repetition Rate " time and providing the initiation switch is kept closed, the sequence will repeat. " Heat Control " enables the plan angle of the welding current to be set to give the required weld heat. **(JN 12)**

Welding Alloys

Pioneers in low temperature welding processes, the Eutectic Welding Alloys Co., Ltd., make a range of welding alloys that cover a wide range of needs and their products have found many applications in the nuclear industry, particularly for the welding of aluminium fabrications. Eutectic welding is based on the work of the Swiss metallurgist, J. Wasserman, who in 1904 first observed the phenomenon of " surface alloying." The research laboratory he established at Lausanne perpetuated his work and gradually in the welding world understanding replaced scepticism of his ideas. In 1940 the Eutectic Welding Alloys Corporation in New York was founded and to-day the organization has factories and depots throughout the world. **(JN 13)**

Widely Used Electrodes

Welding electrodes and equipment made by Murex Welding Processes Ltd., are in extensive use in the nuclear industry, and have been so since the industry's early days. For ordinary mild steel work the " Fastex 5 " and " Vodex " electrodes are used, while " Fortex 35a " electrodes are employed for extra thick plate. The latter were, in fact, specially developed for this purpose. **(JN 14)**

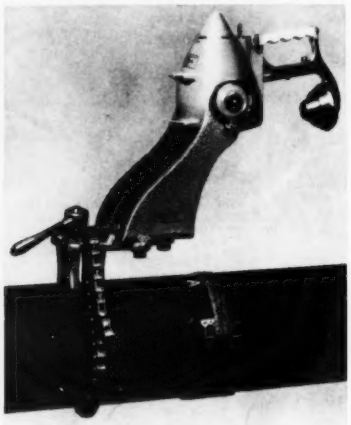
M-V Equipment

The range of welding equipment made by Metropolitan-Vickers covers practically every requirement of the nuclear engineering industry and those supporting industries making equipment for it. It includes plant for both single and multi-operator a.c. and d.c. arc welding; inert gas arc welding, nuclear hydrogen-welding and resistance welding—spot, projection, seam, butt or flash butt welding. In addition, Metrovick have developed a wide range of arc-welding electrodes based on its experience in supplying some of the largest units of power station equipment in use today. Of particular interest is the Tensivick 35v electrode specially designed for all position welding of mild and hard alloy steels such as heavy vessels and structures encountered in nuclear engineering. Metrovick automatic arc welding equipment is available for both submerged arc welding using a bare electrode and granular flux and open arc welding using a flux-coated electrode. The equipment has the advantage that it is readily convertible from one process to the other. A feature of the Metrovick design is the use of electronic control. The Metrovick " Paradyne " is a well tried d.c. welding set with a remarkably smooth and stable welding arc. Sets are available for current ranges between 15 and 300, 30 and 400 amps. Various methods of mounting are available, including trolley mounted engine-driven sets for site work. Also for d.c. welding is the rectifier arc welding equipment, comprising a 3-phase transformer, bridge connected metal rectifier and a transductor for smooth unstepped welding current variation. The control unit for the transductor is fitted with a trailing cable enabling it to be operated at the welding position away from the rectifier. Two ranges of welding current can be easily selected, 30-400 amps and 15-210 amps. The open circuit voltage is 67½v and the arc voltage range is from 25-35v. Another well tried unit, the Metrovick " Thermac " a.c. welder, has recently been redesigned with a number of improvements to the switching and the transformer, enabling its range to be extended without increasing its size. Developments in steam power installations, such as are found in nuclear energy power stations, have emphasized the need for more efficient joining of pipe lines by the employment of butt welds in place of flanges and couplings. This allows the system to be continuous and of much reduced weight. Adding to their very extensive range of flash butt and butt welding equipment, Metropolitan-Vickers have recently built an automatic pressure butt welding machine for pipe lines. For certain classes of welding encountered in nuclear engineering the condenser discharge spot welder is being used. A 40 kVA machine is available with a 36 in. throat depth. It is supplied by a 45,000 microfarad capacity condenser bank provided with links to enable the capacity to be varied. The Metrovick a.c. inert-gas arc welding set has been developed to meet demands for a mobile unit of advanced design for welding light metals and alloys. It has a range of 35-250 amps. In addition to this set, Metrovick have recently made available an H.F. and surge injector unit enabling normal a.c. arc welding sets to be used for inert gas arc-welding of aluminium and aluminium alloys. **(JN 15)**

Irradiation on Sources

Containers for irradiation sources used for testing welds are made by Gamma Rays Ltd., of Smethwick, Staffs. Their model ASS/52B is a lightweight container for up to 2.5 curies of iridium-192. Mounted on a special pipe-clamp it is used for " double-wall " radiography of pipe-welds, its low weight (8 lbs) making it highly portable. Fitted to a powerful magnetic mounting it can be used on site welding, e.g., ship-building, without the need for scaffolding or other special support, a ladder usually being sufficient for the operator. The ASS/52B can also be mounted on a general-purpose tube or

pedestal stand, on which it can be positioned at any angle and at any height from 12 in. to 5 ft 4 in. above ground, making it very useful in radiography in the works. Model ASS/49B is a general-purpose container which will accommodate 300 mC cobalt., 5 curies caesium-137 or up to 30 curies of iridium-192. Weighing 47 lb it is quite portable. This model is designed



Model ASS/49B gamma-rays container mounted on special fitting for the examination of heavy welds in high pressure pipework. Cobalt or caesium-137 can be used as radiation source

so that the isotope can be protruded from it, thus permitting the examination of a circumferential weld in a pressure vessel in one shot. This is done by arranging the container so that the protrusion of the "source," as the isotope is usually called, brings it to the centre of the weld circle. With continuous overlaps of films in flexible holders wrapped around the weld the whole weld is radiographed simultaneously. With its range the ASS/49B will cover the radiography of welds of all sections up to about 6 in. **(JN 16)**

Radioactive Testing

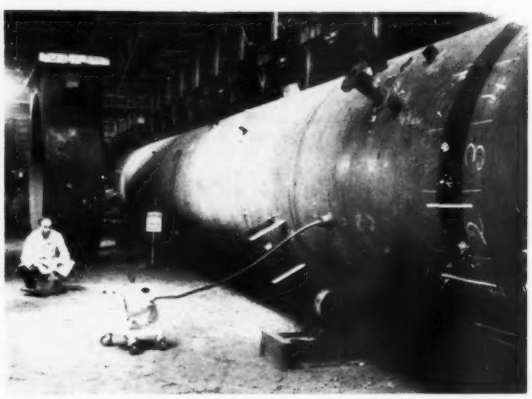
No matter what welding methods may be employed, the rigorous testing of welded seams is of great importance as weld failure in nuclear installations can cause heavy financial loss and even endanger human life. A number of methods of non-destructive testing of welds are in common use, e.g., X-ray, gamma ray, ultrasonics etc. Illustrated on this page is a gamma radiographic container which is used for storage and remotely controlled movement of a radioactive source to any required position. It is made by Nuclear Engineering Ltd. The operator is shown at the remote control box, where a simple mechanical control enables the source to be moved out of the container and along a flexible guide-tube, until it reaches the exposure point. The radiation from the source then penetrates the weld and produces a radiograph on film placed along the seam. The comparative mobility of gamma radiographic apparatus and its independence of power supply, gives this method certain advantages in cases where much weld testing has to be carried out "on site," **(JN 17)**

Radiographic Films

A medium speed, fine grain, high contrast film for industrial radiography for use with or without lead screens (but not with salt screens), Ilford's Industrial CX is recommended for the radiography of light metal castings where fine detail must be shown and for the critical examination of steel welds up to 1¼ in. thick with a 250 kVset. Its inherently high contrast makes Industrial CX very useful for radiography with 1 and 2 m.v. apparatus and with gamma-rays. Industrial CX film is faster than Industrial C, being about twice as fast to 140-250 kVp X-rays and 2½ times as fast to gamma-rays. Its contrast, though not so great as that of Industrial F, is usefully high for a film of this speed, whilst its graininess is actually slightly finer than that of Industrial C. **(JN 18)**

Crack Detection

Several of the standard magnetic crack detectors manufactured by Metropolitan-Vickers are particularly suitable for testing welds. The type "V" crack detector is a mobile equipment of the "current flow" type, with both a.c. and d.c. output, the latter being derived from a germanium rectifier; both circuits are controlled by a "Variac" transformer, giving continuous variation of current between zero and maximum values. All the usual types of current applicators can be used with this crack detector, which is especially useful for testing large structures either during construction or *in situ*. Among the various portable equipments available is the type "PM" crack detector. A high-coercivity permanent magnet is its source of magnetic flux, providing a field strength of 300 lines/sq.cm. in a 3.5 in. air gap. It is of particular use for testing large or inaccessible structures where the examination can be resolved into a number of local tests on suspected



A gamma radiographic container made by Nuclear Engineering Ltd., in use

areas; by virtue of its swivel pole-tips and displaceable pole legs complex shapes can be tested efficiently. As the magnet requires no electric supply for its operation, it is especially suitable for use in coal mines, oil refineries, etc. **(JN 19)**

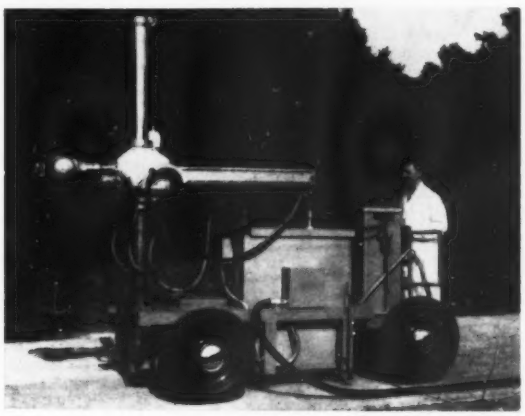
Five X-Ray Films

The range of industrial X-ray films supplied by Kodak Ltd., makes it possible for the industrial radiologist to choose a film with characteristics exactly suited to his needs. There are five types of X-ray films available providing a range of speeds, contrast grades and degrees of resolution to cover every requirement. At one end there is a film of the finest grain suitable for the most critical inspection and at the other a very fast film for inspection where speed is the most important factor. A general purpose film is Kodak's "Industrex" Type S. This has the high speed and contrast vital for the radiography of general industrial subjects and is specially recommended for fault detection in ferrous welds and castings. It can be used with lead intensifying screens where only moderate image contrast is required. "Industrex" Type D film is primarily intended for industrial X-ray work with direct radiation without fluorescent intensifying screens. It is however no less suitable for radiography with lead screens or for all X-ray crystallography where fluorescent intensifying screens are not used. The film is especially valuable for use in gamma ray work. The special characteristic of Kodak "Crystallex" X-ray film is fine grain, so that it is particularly suitable for radiographic records in which fine detail must be revealed. It is eminently suitable, for example, for the radiography of magnesium alloys castings where crystalline porosity is suspected and for examining assemblies for minute flaws. Having an even finer grain than that of "Crystallex" is Kodak "Industrex" Type M. It is suitable for use with high voltage X-rays and for all gamma radiography where the detection of fine faults is most important and it is specially recommended for the very critical examination of light alloy casting and welds, particularly spot welds. The fastest film in Kodak's range of X-ray films is "Kodirex," twice as fast as "Industrex" Type D. It is intended for either direct exposure work or for exposures with lead intensifying screens. **(JN 20)**

Almost Universal

Whilst no X-ray apparatus can claim to be truly universal, the Marconi 250 kV constant potential equipment probably provides the maximum ease of operation in the maximum number of applications. The wide kilo-voltage range—from 30 to 250 kV in 2 kV steps—permits examination of components varying from plastic and aluminium items to ferrous sections up to at least 3 in. thick. The H.T. generator for this equipment is oil-immersed in a welded steel tank and is connected to the

X-ray tube by flexible H.T. cables. The twin Greinocher circuit employed provides a smoothed, electrically stabilized output of a ¼m. volts at up to 15 milliamperes. A feature of considerable importance is that this constant potential generator enables the whole of the high voltage energy to contribute to X-ray generation, ensuring maximum X-ray output and hence exposure times shortened by half. The screened tubehead carries an optional filter/shutter assembly with motor-driven, remotely controlled lead shutters and an automatically acknowledged, interchangeable filter. The tube, which is contained in a shockproof, rayproof shield, is cooled by oil which is pumped into the hollow copper anode whence it flows between the glass envelope and tubeshield to the return pipe. The oil circulator/cooler comprises an oil reservoir with immersed cooling water pipes and an electrically-driven pump which forces the oil to the X-ray tube. The unit, which has temperature, pressure and level gauges mounted on its front panel, incorporates an automatic water valve and temperature and pressure safety switches. There is a choice of tube mounting—gantry, single-column or overhead rail suspension—while a trailer version is available in which the entire equipment is mounted on a wheeled trolley, permitting the easy radiographic inspection of welds and castings, irrespective of size. A self-propelled mobile mounting has also been constructed to carry the tubehand, H.T. generator and oil cooler. This is similar to, though rather smaller than, the trailer, but is powered by an electric motor run from normal 200/250v supply mains. Equipped with steering, the vehicle may be easily manoeuvred about the shop floor, an armoured flexible cable providing connection to the static control unit in its protective compartment. The control unit bears on its front panel all the meters and controls necessary for remote regulation of the exposure. The timer may be set from a fraction of a minute up to 60 minutes, while the tube current is continuously variable from 5 mA up to the maximum rating of the tube. Another Marconi unit is the transportable industrial X-ray apparatus, type TF 1593, which is robust, dust-proofed and spray-proofed, equipment, suitable for field, workshop or laboratory installations. It comprises two transportable units, connected during operation by a low-tension cable; a number of accessories in a metal case are available optionally. The rating of the basic equipment is 5 mA at 175 kVp (continuous) or up to 8 mA for 15 min alternating with 15 min cooling intervals. Use of an optional cooling fan will permit somewhat higher ratings. Also made by Marconi Instruments Ltd., is the new 110 kVp mobile X-ray unit, type TF 1597. Designed for 200-250v a.c. operation, it basically consists of three units—H.T. generator, control unit and tubehead. The method of mounting these units depends upon individual requirements, and the company's X-ray engineers are prepared to advise and design a suitable arrangement to meet any particular inspection problem. Each of the basic units is portable, which makes the apparatus suitable for a wide range of applications in the field of non-destructive testing. **(JN 21)**



The Marconi Instruments 250 kV industrial X-ray apparatus, type TF 1555B, on its self-propelled mobile mounting

Turning Rolls

To facilitate welding operations the boilers for the Bradwell and Berkeley nuclear power stations are fabricated in sections resting on self-propelled turning rolls which enable them to be turned through 180° with ease and comparative speed. Donald Ross & Partners Ltd., of Crawley, Sussex, who supplied the rolls, also supplied other manipulating and positioning equipment used in the boiler fabrication. The firm is also engaged on special equipment for welding the reactor vessels for Hinkley Point. **(JN 22)**

Cleaning Weld Surfaces

It is essential that all metallic surfaces must be absolutely clean before and after welding takes place. Corrosion products, millscale and weld slag must be removed if the welds are to meet the stringent requirements imposed by modern specifications. Chipping, grinding and scratch brushing each have their own uses for this purpose. Another method of removal is by the grit blasting technique, developed by Vacu-Blast Ltd. In this method the blast can be directed and used in a localized area with the precision of a paint brush and a manoeuvrability equal to that of a welding electrode. Furthermore, it enables the operator to work in any location or position, whether it be at ground level in a crowded shop, inside a boiler drum or on a scaffolding 100 ft above ground level. No additional protective clothing is necessary. Vacu-Blast is used extensively for weld preparation in securing a thoroughly cleaned oxide free of area in the machined preparation or butt joint immediately prior to deposit of the weld metal. In multi-pass welding it is used for removing slag between each pass. For cleaning mating edges of plate for fillet welding a special attachment known as the Dual Gun is available. Similarly the included edge angle in a box section is cleaned by fitting an angle brush on the standard gun attachment. When Vacu-Blast is applied to stainless steel aluminium and the nimonics a non-ferrous abrasive is used to preclude ferrous contamination of the work surface. **(JN 23)**

Hole Cutter

An oxygen cutting machine specially designed for cutting non-radial holes in reactor vessels for receiving charge tubes has been developed by Oxhycarbon Co., Ltd. It will also bevel the edges of the holes both inside and outside the vessel in preparation for welding. The machine which is supported by four adjustable legs, consists of an arrangement of frames enabling the actual cutter to be operated at any angle, and for the cutting of any type a variety of shaped holes. The cutter is operated by remote control. A special indicator is provided to assist in the accurate and consistent adjustment of the machine. **(JN 24)**

Production Welding

Among firms specializing in resistance welding equipment are the British Federal Welder and Machine Co., Ltd. They design and manufacture all types of units, from 1 kVA to 1,500 kVA models, or even with larger outputs if required. Equipment includes fully automatic conveyor and feed lines for high production requirements in all types of industries. **(JN 25)**

Welding Contractors

The welding techniques employed by Hall Engineering Ltd., at their Shrewsbury Works cover almost every known method from light oxyacetylene for the welding of light gauge sheet metal to arc welding of mild steel structures up to plate 8 in. in thickness. Methods used include, a.c. and d.c. electric arc welding for mild and alloy steels, argon arc welding for stainless steel and aluminium, atomic hydrogen welding for vacuum work, submerged arc welding for pressure vessels, stud welding where appropriate, oxyhydrogen flame cutting for steel and powder cutting for flame cutting stainless steel. Particular attention is paid to quality and the inspection department is equipped with the latest ultrasonic testing equipment for detecting plate laminations and a 250 kV X-ray machine for the examination of welds. Special precautions are taken to ensure that welding electrodes are stored under correct and controlled conditions of temperature and humidity. Recent contracts completed by Hall Engineering include work on an experimental facility for DIDO (UKAEA, Harwell), heavy steel shielding doors 12 in. thick for nuclear reactors, stainless steel vessels for the chemical industry, aluminium structures for armament work, and supersonic wind tunnels. **(JN 26)**

PEOPLE... in the NUCLEAR NEWS

SIR JOHN COCKCROFT, OM, is one of the seven eminent scientists appointed to serve on the Scientific Advisory Committee of the International Atomic Energy Agency. The others are **PROFESSOR H. J. BHABHA,** chairman of the Indian Atomic Energy Commission, **PROFESSOR V. S. EMELYANOV,** chief of the Central Board on the Use of Atomic Energy of the U.S.S.R. Council of Ministers, **PROFESSOR B. GOLDSCHMIDT,** director of the chemistry department of the French Atomic Energy Authority and of the authority's external relations department, **PROFESSOR B. GROSS,** head of the department of electrical measurements at the National Institute of Technology, Brazil, **PROFESSOR W. B. LEWIS,** vice-president for research and development of the Atomic Energy of Canada Ltd., and **PROFESSOR I. I. RABI,** chairman of the general advisory committee of the U.S. Atomic Energy Commission. The function of the advisory committee is to provide the governors and director general of the IAEA with advice on scientific and technical questions arising out of the Agency's programme. Among the first points to be considered by the committee are the IAEA's programme for conferences and symposia to be held in 1959 and subsequent years, a proposal for estimating the world wide distribution of hydrogen and oxygen isotopes in water, the establishment of the Agency's functional laboratory, IAEA's long range need for technical facilities, and additional activities the committee might recommend as additions to the Agency's programme.

Nuclear Chemical Plant Ltd., the company recently formed by the Power-Gas Corporation Ltd., Humphreys and Glasgow Ltd., and John Thompson Ltd., for the design and engineering of process and treatment plant for the nuclear industry have appointed **MR. R. W. RUTHERFORD,** MIGasE, MIChemE, MInstF, as chairman. Appointed deputy managing director of The Power-Gas Corporation in 1953, Mr. Rutherford has been a director of the corporation since 1948 and is also a director of an associate company, Rose, Downs & Thompson Ltd. For many years he lived in Japan promoting the firm's business in the Far East and since his return to the United Kingdom has travelled overseas extensively. Other directors of the new company are **MR. G. GRESLE FARTHING,** deputy chairman and joint managing director of Humphreys

Mr. R. W. Ruthertord

and Glasgow Ltd., and **MR. J. N. H. THOMPSON,** MIMechE, deputy chairman and joint managing director of John Thompson-Kennicott Ltd., **MR. C. ROBSON,** a director of the Power-Gas Corporation Ltd., and **MR. N. H. WILLIAMS,** a director of Humphreys and Glasgow Ltd., have been appointed alternate directors.

General manager of Nuclear Power Chemical Plant Ltd., is **MR. R. JOWITT,** BSc,(Eng.), AMIMechE, AMIChemE. In the chemical plant industry for over ten years, he joined Humphreys and Glasgow Ltd., three years ago and since then has been concerned with gas purification, ore treatment, and process aspects of nuclear energy. Some of Mr. Jowitt's staff are at present being trained in nuclear subjects by the UKAEA at their Industrial Group headquarters, Risley. They are **MR. J. S. JONES,** MS, BA, **MR. E. G. SPALDING,** BA, and **MR. N. E. WILLIAMS.** Mr. Jones, from Humphreys and Glasgow Ltd., joined that firm in 1953 and has been working as project engineer and sales engineer in their gas and nuclear departments. In 1956 he went to the U.S.A. to spend a year's study course on a Sir Stuart Goodwin fellowship. Mr Spalding, from John Thompson Ltd., was for five years an engineering apprentice at the Royal Aircraft Establishment Technical College, Farnborough and then worked in the Rocket Propulsion Department of the Ministry of Supply. In 1951 he joined John Thompson as a nuclear project engineer. Mr. Williams, the third Nuclear Chemical Plant man training at Risley, has been working as project engineer with The Power-Gas Corporation, before which he was an engineer with Head Wrightson & Co., Ltd.

(*From right to left*): Mr. J. S. Jones, Mr. N. E. Williams and Mr. E. G. Spalding

PROFESSOR A. D. BAXTER, MEng, MIMechE, FRAeS, FInstP, chief executive of the rocket division and nuclear power group of the De Haviland Engine Co., Ltd., has been appointed to the board of directors. Professor Baxter joined the company in 1957 from the College of Aeronautics, Cranfield, where he was deputy principal. Before that he was Professor of Aircraft Propulsion and in that capacity built up the college's extensive component and engine test facilities. Educated at Liverpool University, Professor Baxter was from 1930 to 1934 an

Professor A. D. Baxter

apprentice with the Daimler Co., and then became a research engineer at the Institution of Automobile Engineers. In 1935 he joined the Royal Aircraft Establishment and was initially concerned with the flight development of exhaust-driven turbo-blowers. With the advent of the aircraft gas turbine his subsequent career with the RAE was closely associated with the pioneering of jet propulsion. In 1944 he joined the newly formed gas dynamics and supersonics division of the RAE where he worked on ramjet and rocket research. For three years he was the first superintendent of the RAE's rocket propulsion department at Westcott. Then in 1950, he was elected to the newly created chair of aircraft propulsion at Cranfield.

To manage the Scandinavian company of the Solartron Electronic Group, which is in the course of formation in Sweden, is **MR. KURT P. KALLGREN.** Thirty-eight years old, he was born in Stockholm, educated in Sweden and, after completing commercial and technical studies, joined the Royal Swedish Air Board in 1946 as a purchasing officer at their headquarters in Stockholm. In 1950, the Air Board posted him to England where he worked at the Embassy as commercial assistant to the air attache until the end of 1952. In 1953, he was appointed assistant manager at the London office of the SAAB Aircraft Co., and Royal Swedish Air Board.

NUCLEAR ENERGY DEVELOPMENT IN Europe

Research and power developments in Sweden, Norway, Denmark, Finland and the Netherlands are discussed by the author in this month's contribution to his series on how the world is harnessing nuclear energy. Countries already dealt with are Britain, France and Germany. Next month the author will touch on Belgium, Italy, Spain and Portugal

by J. BURKETT

SWEDEN

SWEDEN has no coal or oil deposits worth mentioning but the potential annual output of hydro-electric power is estimated at about 80,000m. kWh, of which some 25,000m. kWh is currently being produced. With the demand for electricity rising at the rate of 6½ per cent. per annum, reserves of water power are therefore sufficient for the next 15-20 years.

In the 1954 figures for the specific electricity consumption in various countries, Sweden's annual consumption stands very high:—

	kWh/inhabitant
Norway	6,484
U.S.A.	3,393
Sweden	3,267
Gt. Britain	1,585
Belgium	1,202
France	1,054
Denmark	749

Sufficient progress will have to be made, before all Sweden's water power resources are fully utilized, in developing reliable and economic nuclear power stations for the provision of electricity at a competitive price. This is important because Swedish industry enjoys cheap electricity at half the price obtained in this country.

The State Power Board estimates a demand for 500 MW of nuclear power capacity by 1965 with 6-7 district heating reactors. If the early plants prove successful then the annual increase should be of the order of 150 MW. A Swedish Government Survey suggested that up to 100 heat reactors would be required by 1980 but this has been criticized as too ambitious a forecast.

Fuel Programme

Sweden's programme has been based on the use of natural uranium, of which there are considerable national deposits, and heavy water. There has been some consideration, however, of using enriched fuel and light water for reactors of smaller heat outputs and for ship propulsion. Under a bilateral agreement with U.S.A., Sweden can obtain 12 kg. of U-235 enriched up to 25 per cent. A further agreement with the UKAEA facilitates the purchase of British research reactors and fissionable material. Estimated future demands for natural uranium are: 1960—20 tons per annum; 1965—75 tons per annum; 1970—200 tons per annum.

The uranium processing plant that is being built close to the Bellingen deposits by a British firm, should be completed by 1962, for the annual production of 120 metric tons of uranium metal, i.e., 900,000 tons raw shales.

Home Produced D_2O

Although heavy water requirements have so far been met by purchase from Norway and the U.S.A., plans have been completed by ASEA for home production at two-thirds of the current price. The plant is designed to give an annual output of 20 tons which can be increased to 100 tons later in stages.

Some Swedish towns already have district heating systems supplied by oil-fired units. Future demands are likely to expand to the 70-200 MW range and it is this field that holds promise for nuclear power in the effort to save oil imports.

Space Heating

The R-3 reactor system designed for supplying space-heat to the 12,000 apartment housing estate at Farsta, will probably produce 10 MW of electricity by back-pressure turbine methods. With an oil-fired superheater the station will be able to generate 47 MW(e) or 36 MW(e) when supplying 70 MW of heat to distribution water.

The operation of R-3 will provide information for the development of steam producing reactors for the pulp and paper industry and for R-4 (EVE).

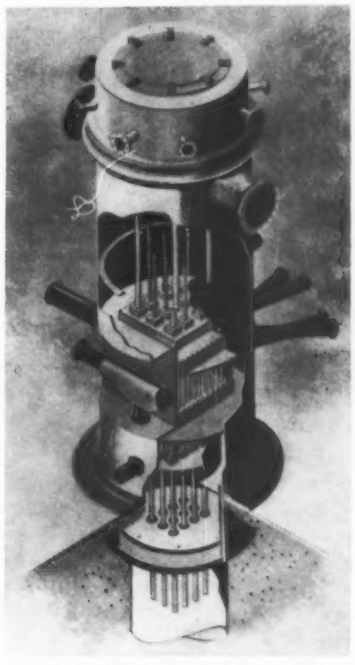
The reactor ADAM which was to have supplied district heating at Vasteras, has been cancelled on the grounds of cost, which has more than doubled since the last estimate was made (100m. crowns) over two years ago. Effort is therefore being concentrated on the R-3 project and the reactor for this plant will now be called R-3/Adam. The cost of the Farsta plant is estimated at about 115m. crowns (nearly £8m.).

The power station EVE with the reactor R-4 is the result of pooling the design efforts of the State Power Board and AB Atomenergi. If the completion date of 1964 is to be upheld, it is quite likely that an English or American type reactor may have to be used. The interim period appears too short for a new Swedish development.

Apart from State sponsored schemes it is reported that ASEA is investigating the feasibility of a "medium temperature" reactor for heat and power, with an oil-fired superheater and a 35-40 MW heat plant using enriched uranium.

Three of the leading companies interested in nuclear marine propulsion are Gotaverken, Rederi AB Nordstjernan and Kockums.

Rederi AB, part of the Johnson Group, plan to build a land-based prototype



30 MW light water reactor materials and testing reactor supplied by ACF Inc., of America, for AB Atomenergi, Sweden

reactor to supply power to the group's petroleum refinery. An agreement has been signed with Westinghouse for collaboration in the development of a high temperature gas-cooled type.

Kockums in Malmo have prepared a preliminary design for an enriched, light water reactor that would not only act as a land-based prototype ship reactor but would also provide power to an area badly in need of it.

AB Gotaverken has designed a 65,000-ton tanker developing 30,000 s.h.p. powered by a boiling water type reactor, steam from the core being fed direct to the turbines. With only 1 per cent. enrichment, the relatively large amount of uranium gives an irradiation time of 2.2 years and lower fuel costs.

It is reported that the shipyard Uddevallavarvet may power the third of the three projected 65,000-ton tankers it will build with a General Electric reactor.

Further details can be obtained from the following papers presented at the 2nd International Conference on the Peaceful Uses of Atomic Energy:—P/135—R.3; P/136—Adam; P/172—Design and containment of nuclear power stations located in rock; and P/173—Safety and location of atomic energy plants in Sweden.

Drawing to show the R-3 nuclear reactor plant designed for supplying heat to 12,000 dwelling houses at Farsta, Stockholm

NORWAY

THE predominant source of power in Norway is water, which is responsible for 99 per cent. of the total energy produced. Wood and peat are used for domestic heating.

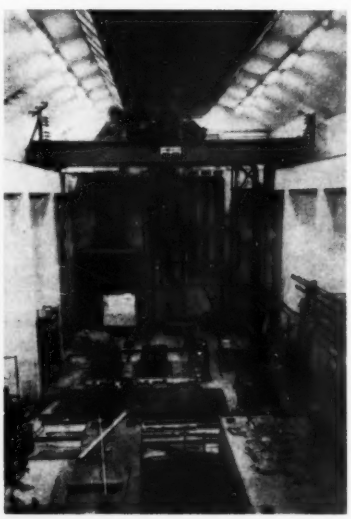
About a quarter of the potential all-year capacity has been exploited, 26 per cent. of which is owned by the state, 39 per cent. by local authorities and 35 per cent. privately owned.

In 1954 just over 19,000m. kWh of electricity were consumed (62 per cent. by industry); by 1960 this is expected to increase to 30,000m., which signifies the installation of an additional 300 MW each year. Based only on the utilization of all-year capacity hydro-power and assuming the country has the technical and financial resources, potential water power will be fully exploited within 30 years.

Whilst Norway is not urgently needing nuclear power it is actively interested in developing techniques for the production of process heat plants for paper production and for ship propulsion. The possibility of exporting reactors is another likely factor.

The main research centre is the Norwegian Atomic Institute at Kjeller near Oslo, founded in 1948. Activities include reactor engineering, physics, isotope production and ship propulsion studies. Of the 200 staff, 30 foreign scientists, mainly from the Netherlands, help to operate the bilateral Joint Establishment for Nuclear Energy Research (JENER).

The major experimental facility is JEEP, a 700 MW (heat) natural uranium, heavy water moderated and cooled reactor which became critical in 1951. Thermal flux is 2.5×10^{12} n/cm^2/sec. The 2.4 tons of fuel came from the Netherlands, whilst the heavy water was manufactured locally in the plant handled by the Norwegian Nitrogen Company.

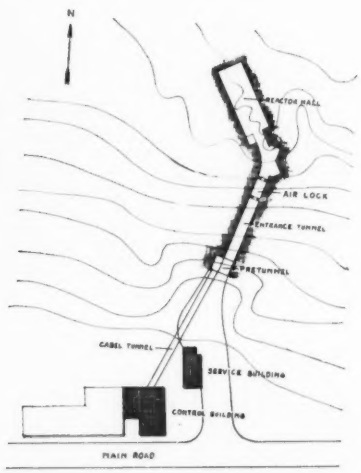


View of the reactor hall (*above*) and the tunnel entrance (*left*) of the 20 MW boiling water reactor project at Halden, Norway. Layout of the plant is shown on the right. Experience gained with this plant will be used for the development and construction of a full scale industrial station

Norway's second reactor is the 20 MW (heat) boiling heavy water at Halden, a project which is essentially financed by the government although Norsk Hydro carries part of the expense for heavy water, whilst experimental and development costs are covered by IFA.

The uranium fuel elements that are being supplied by the UKAEA are clustered spikes with enriched UO^2 pellets canned in steel tubing to enable operation to maximum temperature (150°C.). It has been sited at a paper and pulp firm so that the by-product steam (at 230°C.) can be put to a useful service.

Unlike JEEP, which is contained in a normal gas-tight type of ordinary concrete masonry construction, Halden's reactor is housed in a hall excavated in solid rock,



which provides coverage varying in thickness from 100-200 ft. This was an important factor in siting the reactor only one kilometre from a town of 10,000 inhabitants, over 2,000 of whom are living or working within half that distance.

The principal industrial group with nuclear energy interests in Norway is NORATOM, consisting of some 40 companies including leading iron and steel and wood processing firms, bankers and ship owners. The company will co-ordinate the production of nuclear equipment and organize oversea markets.

Further details can be obtained from the following papers presented at the 2nd International Conference on the Peaceful Uses of Atomic Energy:—P/571—The Netherlands-Norwegian reactor school; P/585—JENER reprocessing pilot plant; P/1475—Recent experiences with the Kjeller heavy water reactor JEEP; P/559—The Halden boiling heavy water reactor; and P/561—Underground location of a nuclear reactor.

FINLAND

ELECTRICAL energy in Finland is primarily supplied through water power. The only other fuels are wood and peat. After World War II with the cession of part of her territories, Finland lost considerable utilized hydro-power and industrial districts. Consequently, hydro resources will be fully exploited within 15 years. Consumption of electrical energy in 1954 was 5,480m. kWh and this is estimated to reach 9,750 by 1960 and 21,000m. in 1970. The full utilization of potential hydro-power involves enormous investments, which may prevent the fruition of such an extensive construction programme.

Apart from domestic fuel production, much of which is used locally for heat, the amount of imports currently is about 3½m. tons of coal, coke and liquid fuels and this is expected to increase to about 4½m. by 1960.

There is, therefore, a strong case for the early introduction of nuclear power plants to provide power, domestic heat and process steam for the woodworking industry.

Forecasted installed capacity: 100 MW by 1960 (representing 8 per cent. of total power production), 200 MW by 1965 (representing 10 per cent. of total power production), and 600 MW by 1970 (representing 20 per cent. of total power production).

The only plan existing so far for nuclear power development is the construction of a 1 MW experimental pile at Helsinki, by a syndicate of Finnish firms—Voimayhdistys Ydin. A bilateral agreement with the United Kingdom in 1957 allows for the supply of up to 150 kg of natural uranium.

DENMARK

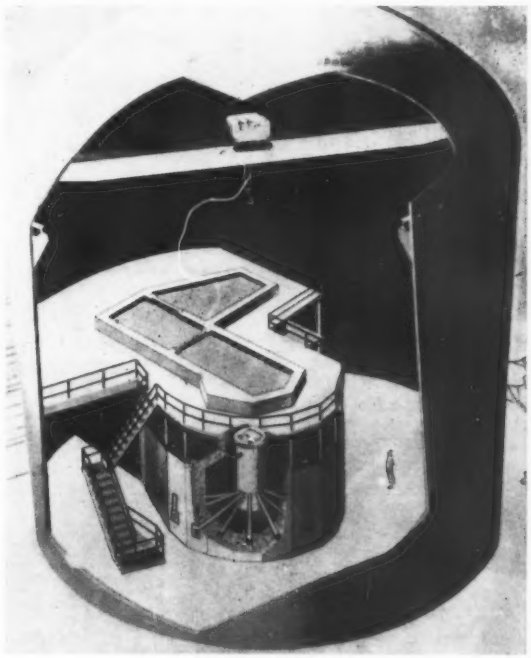
MORE than 50 per cent. of Denmark's fuel has to be imported and this represents a considerable burden to the country's economy.

At the same time, energy consumption has been increasing at the high annual rate of nearly 10 per cent. Present fuel imports are in the region of 2m. tons, a figure that will be doubled by 1965 if the present rate of increase continues. Denmark has been able to keep its production costs down by burning large proportions of inferior coal.

Low Load Factor

Supplies of this are limited and future usage of better quality coal and oil will result in a sharp rise in generation costs to a level which makes nuclear power competitive. On the other hand, the load factor is as low as 31.4 per cent., a factor which presents a considerable problem when related to the economic operation of nuclear power stations.

Nevertheless, the need for reducing the dependence on and cost of fuel imports is urgent and studies have begun on two nuclear power stations.



20 MW light water materials testing and research reactor supplied by ACF Inc., of America for Reactor Centrum Nederland, at Petten

RISO The Centre

Nuclear activities are directed by the Danish Atomic Energy Commission, who have established a research centre at Riso, near Copenhagen. The first reactor (DR-1) which started up in August, 1957, is a zero energy boiling water type of American design. DR-2, a 5 MW (thermal) tank type research reactor, is also being built by an American company. An early agreement with U.S.A. for reactor fuel was amended to enable the maximum of 50 kg of U-235 to be used, the bulk of which will go in DR-2.

The third reactor, for materials testing, is a " Pluto " type built by an English firm, Head Wrightson Processes, Ltd.

Industry is represented by the organization DANATOM, formed from the major electric power companies, engineering and shipbuilding firms. Groups are studying nuclear power station designs.

The NETHERLANDS

AT the moment the Netherlands is obliged to import 47 per cent. of its total energy requirements. With an estimated 6.5 per cent. per annum increase in electricity demand up to 1975, the national fuel deficit in 1960 will probably be 55 per cent. of total requirements and 67 per cent. by 1975. The climbing increases in coal and oil prices will cause the operational expenses of conventional power plants to rise also.

A recent study of the application of nuclear power to electricity supply has convinced the government that nuclear power generation is economically justified. In July, 1957, an official memorandum stated that the country would need to take up nuclear power at once without waiting for foreign reactors to reach the highest degree of perfection.

A programme has been promoted for the construction of nuclear power stations, the responsibility for which will be mainly in the hands of independent power supply companies. The first station (100 MW) is planned for 1962 with an additional station each year up to 1965. By this time nuclear power should provide nearly 12 per cent. of the total electricity output. The programme will then be increased so that by 1975 over a third of the total installed capacity in the form of nuclear power stations will provide 51 per cent. of the total output.

Joined with Norway

Netherlands started its nuclear research as early as 1951 when it became partner with Norway in founding JENER for the organization of the Kjeller research and training centre and the running of the JEEP reactor.

Much of the future effort of JENER will be devoted to the study of the boiling water reactor at Halden.

The principal research organization, founded in 1955, is the Reactor Centrum Nederland. The government has a 25 per cent. interest whilst the rest is shared by electricity companies, learned institutes and industry. Two research reactors will be in operation by the end of this year. One is a 20 MW materials testing reactor, light water moderated and cooled, fuelled with 90 per cent. enriched uranium. It is to be supplied by the U.S.A. This high flux reactor, sited at Petten near Amsterdam, is being supplied by ACF Industries, of New York. The second is a 100 kW swimming pool type supplied by AMF Atomics of New York with 20 per cent. fuel enrichment. The reactor was first operated in 1957 at the International Atomic Energy Exhibition at Amsterdam. It has since been removed to Delft where it will be at the disposal of all the universities in the Netherlands for research, the training of operators and for small production of radio-isotopes.

The KEMA research centre formed by electricity undertakings at Arnhem is studying suspension reactors in which the fuel is held in suspension in fluid materials.

(*Above*) **Construction in progress on site of 20 MW research reactor at Petten, Holland.** (*Top right*) **Reactor vessel and beryllium oxide reflector for the zero energy homogeneous reactor at the KEMA Institute, Arnhem.** (*Right*) **The control room to this reactor**

Zero energy experiments are being made, a 250 kW type is under construction, the next step being a 10-30 MW (heat) test reactor. Further study is being made of the dry suspension system.

Further details can be obtained from the following paper presented at the 2nd International Conference on the Peaceful Uses of Atomic Energy:—P/1828—Development of a 250 kW aqueous homogeneous single suspension reactor. (*For JENER see under Norway.*)

(*To be continued*)

Literature Received

FROM George Kent, Ltd., comes a 36-page booklet on "Measuring and Controlling Nuclear Energy." In simple lucid terms it briefly explains the various types and methods of instrumentation used in nuclear energy establishments and photographs illustrate some of the many nuclear projects, both in the United Kingdom and overseas, in which Kent instruments are used. A glossary of nuclear terms is given at the back of the booklet.

* * *

IN 39 pages, "Rocol Molybdenised Lubricants No. 3D" explains what molybdenum disulphide is, describes the range of molybdenised lubricants manufactured by Rocol, Ltd., and their use, and carries extracts from "user reports." In less than a decade Rocol Ltd., have developed 28 specialized lubricants using molybdenum disulphide and with application in almost every conceivable industry. Rocol was responsible for solving the problem of the permanent dry lubrication of nuclear reactor control rod mechanisms, which once installed, cannot be "oiled" again.

* * *

"THIS is Magnesium," published by the Magnesium Industry Council, deals with the properties and uses of magnesium and its alloys. With many advantageous properties to its credit magnesium has application in many branches of the engineering industry and it is hoped that this booklet will introduce the metal to many new potential users. Copies can be obtained from the Council, 15, Took's Court, Chancery Lane, London, E.C.4.

* * *

INSPECTORS, welding engineers, designers and fabricators of aluminium alloys will be interested in a new booklet H3/58, published by the British Welding Research Association, which shows how to identify those defects in aluminium fusion welds which can be seen in radiographs. The defects are classified, their origin explained and suggestions for their prevention are made. The booklet was prepared by the senior metallurgists of the association with the help of experts from industry.

* * *

"A NEW view of a well tried tube" proclaims the cover of a brochure describing the recently enlarged range of wire wound heat exchanger tubes manufactured by the Clayton Dewandre Co., Ltd. Inside are details of the properties of the tubes and descriptions of the various types that are available. The brochure can be obtained free of charge from Clayton Dewandre Co., Ltd. Titanic Works, Lincoln.

* * *

A FOLDER to introduce business executives to E.M.I. Electronics closed-circuit television equipment has been produced. The folder, in two colours on art paper, describes various applications, ranging from visual control of several widely-separated operations, observation of dangerous processes, training and surveillance at sales conferences and demonstrations, and the transmission of blue-prints, etc.

NUCLEAR NEWS

- **Food Irradiation Conference** *(This page)*
- **Harwell Cyclotron Equipment** *(Page 66)*
- **New Science Exhibition** *(Page 68)*

THE need for international co-operation in research on food irradiation was stressed at the recent FAO European Meeting on the use of Ionizing Radiations for Food Preservation. European governments were urged to give serious consideration to developing and encouraging research in this field. The meeting, which was held at the AERE, Harwell, was attended by 179 representatives of 17 European countries, and observers from four non-European countries and 14 international organizations. Papers reviewing progress made in food irradiation were presented by specialists from European countries and the United States. Not only was the use of ionizing radiations for the treatment of food in order to extend its storage life discussed, but also the disinfestation of foods, the suppression of sprouting in potatoes, and root crops, and the inactivation of organisms undesirable from the public health standpoint. Though much progress has been made over the past few years in research in this field the meeting recognized that there was still a great deal to be done in overcoming the various technical, economic and wholesomeness problems involved before food irradiation could be developed on a widespread commercial scale.

Sales Exhibition

A WIDE range of electronic equipment and instruments is displayed at the permanent sales exhibition staged by E.M.I. Electronics Ltd., at their Hayes, Middx., headquarters. Of direct application in the nuclear field are the recently-introduced EMIRAD Hand and Clothing Monitor Type I sets. These are unique in that they can detect simultaneously two types of contamination on the hands. This is achieved by the use of a system of dual phosphor scintillation developed by EMI. Closed circuit television is demonstrated and there are various types of cameras on view. A new development of EMI on show is FRED, a Figure Reading Electronic Device which can read either optically or magnetically.

Italy's First

THE foundation stone of Italy's first nuclear power station was recently laid. The event was attended by many distinguished guests, including Lord Mills, the British Minister of Power and Sir Ashley Clarke, British Ambassador to Italy. The station, which is at Latina, 40 miles south of Rome, is to be built by the Nuclear Power Plant Co., Ltd., of Knutsford, Cheshire. Based on the Calder Hall prototype, it will have one graphite-moderated gas-cooled reactor with a design output of 200 MW. AGIP Nucleare, owners of the station, will undertake the civil engineering work, in close co-operation with the NPPC, and will be responsible for the manufacturing and testing of components built in Italy. The British company are responsible for the overall design of the station and its commissioning and will supply all the major components, including the reactor itself, boilers and turbines. The station is due to be ready by 1962. At the foundation stone ceremony Ing. Enric Mattei, president of Ente Nazionale Idrocarburi, the state corporation responsible for exploitation of Italy's natural gas sources, and the parent company of AGIP Nucleare, threw a symbolic parchment into a concrete trench. Mgr. Gasbarri, Auxiliary and Vicar-General of Velletri, blessed the stone. The night before, an inaugural dinner was held in Rome at which the guest of honour was the Italian Prime Minister, Onorevole Amintore Fanfani. Other guests included Sr. Giorgi Bo, Italian Minister for Industry, Ing. Mattei, Lord Mills, Sir Ashley Clarke, and Sir Leonard Owen, managing director of the Industrial Group of the UKAEA. Host was Sir Claude Gibb, chairman of the NPPC.

View of the site of the nuclear power station to be built by the NPPC for AGIP Nucleare at Latina, near Rome

Part of the ceremonies attached to the laying of the foundation stone of Italy's first nuclear power station was the embedding in concrete of a parchment signed by the principal parties to the construction contract. Ing. E. Mattei, president of ENI, is seen here throwing the parchment contained in a metal cylinder into the concrete

TV for Latina

A CONTRACT to supply television equipment to the first Italian Nuclear Power Station at Latina has been awarded by the Nuclear Power Plant Co., to Pye Ltd. The equipment will be similar to that being supplied to the CEGB station at Bradwell which is now under construction.

Welding Centre

AN information centre has been established by the American Welding Society, 33, West 39th Street, New York City, for the dissemination of welding news and information. The new centre fills a long felt need. It will act as an authoritative source for all information related to welding. This service will be of substantial benefit to both the press and industry. The press will be able to check with the centre for technical accuracy, verify news items, obtain additional facts and details to make a story or article complete and, in many instances, obtain photographs to illustrate material. Industry will benefit by the release of news, technical information and the like. The centre will be concerned with information related to the welding industry as a whole; products, equipment and personnel are regarded as company matters and will be handled by individual companies.

Welding Show

MOBILE radiography units which have been operated by Mitchell Engineering Ltd., for some years were on show recently at the firm's headquarters at Peterborough, together with exhibits of various aspects of Mitchell's welding activities. At the present time radiography inspection units are used mainly in conjunction with Class I high pressure pipe welding of steam and central power stations. The units are, however, finding increased use in the inspection of more difficult welding undertaken on nuclear contracts. This work involves the inspection of welded pipe connections made of the argon arc processes in stainless steel, Monel metal and Inconel, all of these materials being, at present, welded in position at site. With temperatures and pressures now in the range of 2,000 lb/sq.in. and 1,000 F., and use of highly toxic fluids particularly in nuclear work, it is more than ever essential to ensure the safety and top efficiency of plant under construction. The mobile units carry out materials' checks using gamma ray inspections on site, and their use considerably speeds up fabrication work. They are found to be ideal because most of the work undertaken is of comparatively short duration at widely scattered points.

UKAEA Contract

ONE of the oldest established firms in the industry, yet right up to the minute in outlook and techniques, Hill & Smith Ltd., of Brierley Hill, Staffordshire, have been appointed by the United Kingdom Atomic Energy Authority as structural steelwork contractors at the Harwell Research Establishment for the next two years. Their contract was awarded on the basis of an intake into Harwell of 600 tons. Hill & Smith obtained their first structural contract for the UKAEA at Harwell in 1958.

NUCLEAR NEWS

Within six months, ten orders had been received, covering a wide range of structural and fabricated steelwork; office block beam and column work; various flat and pitched workshops, some including crane tracks; site welded portal frames; plated floors and platforms; self-supporting crane gantries; weldmesh partitions, storage racks and trays.

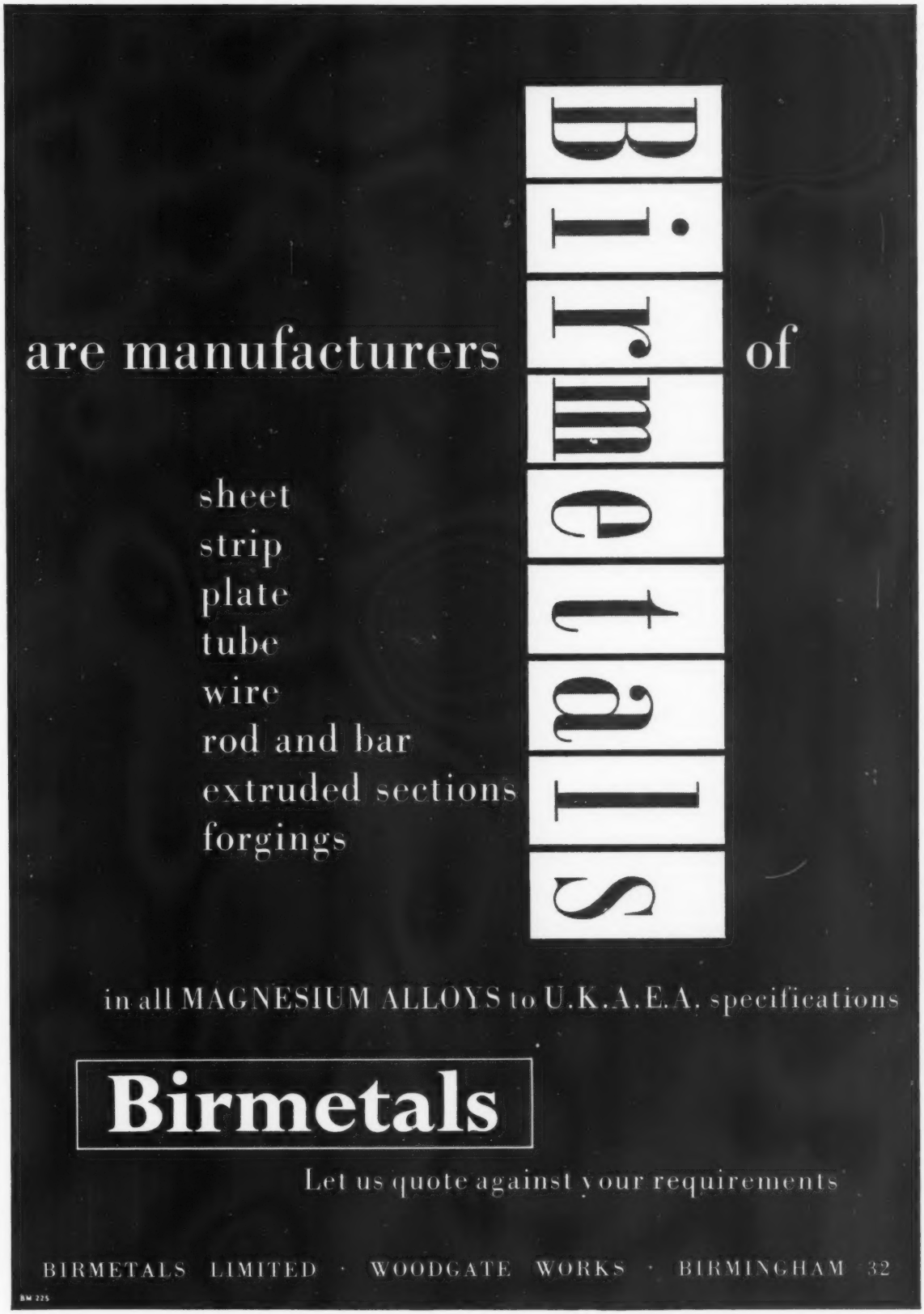
"W.S.A. Report"

JUST announced by Eutectic Welding Alloys Co., Ltd., of Feltham, Middlesex, is a new free consultative service to welding users in British industry. Already tried and proved with many thousands of medium and large users in Europe and the United States, Eutectic's Weld Savings Application Report Service provides a speedy and comprehensive analysis of the time and material savings which should be operating in maintenance welding shops. It covers salvage and repair problems which can be overcome with low temperature welding techniques, using both oxy-acetylene and electric arc equipment. The "W.S.A. Report" consists of a check-form, listing parent metals and industrial operations on which maintenance welding is commonly used. Space is provided for classification of the user's own operations and his particular problems, sectionalized to show the most economical methods and the actual values of the savings which are possible. Problems not immediately solved by the analysis form can be noted for individual study.

Cyclotron Plant

TWO contracts worth just under £1m. have been placed by the National Institute for Research in Nuclear Science with British Brown Boveri Co., Ltd., and English Electric Co., Ltd. They are for equipment for the 7 GeV proton synchrotron to be built at Harwell. Brown Boveri will supply the converter plant at a cost of £500,000 and English Electric the rotating machinery for £470,000. The converter plant will include excitrons, which are large mercury vapour switches, timing and control equipment and transformers. The essence of the rotating machinery will be a 120 MVA machine set weighing 280 tons and comprising two alternators, two flywheels, and two driving wheels, all coupled together on the same base. The function of this set will be to provide the current pulses for energizing the coils of the synchroton's electromagnet. The synchrotron, which is being built for the Institute by the UKAEA, will be sited in the Rutherford High Energy Laboratory.

Night Scene at CHAPELCROSS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Top Scientists Relax

Sir John Cockcroft and Mr. A. N. Nesmeyanov, president of the Soviet Academy of Sciences, chatting together at a reception given by the Academy president during Sir John's recent tour, with other British physicists, to Russia

New Exhibition

A NEW exhibition is to be held at Olympia in October this year. It is the International Scientific Research Exhibition, organized to illustrate the story of scientific achievement; to demonstrate the influence scientific development plays in our daily lives, and to explain the promise scientific discovery and research holds for the future. Four main themes have been chosen as the pattern for the exhibition: Health and Food—Materials—Transport and Communications—Power and Industry. For the first time universities are being encouraged to take part in a public exhibition so that they can make known the very important part they are playing in modern technical and scientific research.

Graphite on Film

ATOMICS International, a division of the North American Aviation Inc., have announced that they have successfully recorded dislocations and imperfections in the structure of graphite on 16 mm cine film. Filming was carried out through an electron microscope using a camera fitted with a special lens of f/0.95 and loaded with high speed film. Graphite specimens were photographed at magnifications of 12,500 and 25,000. Only lighting was that from the microscope screen.

Russian Welding

THE British Welding Research Association is undertaking the latest cover to cover translation from the Russian. Regular translation of "Avtomaticheskaya Svarka" (Automatic Welding) will start with the January, 1959, number. This is expected to arrive in Britain in March and will be distributed in translation to subscribers in late April or May. "Avtomaticheskaya Svarka" deals with equipment and methods of welding, metallurgy, the strength of welded work generally, and fatigue testing. The journal is about 12 years old, and was issued six times yearly until January, 1958 when it began to appear monthly. It is the organ of the Arc Welding Institute of the Order of the Red Banner of Labour at Kiev in the Ukraine, the Institute being a section of the Ukrainian S.S.R. Academy of Sciences.

Our Stand at Olympia

PRINCES Press Ltd., publishers of NUCLEAR ENERGY ENGINEER are to exhibit at the Engineering, Marine Welding and Nuclear Energy Exhibition, Olympia, London, April 16th-30th. Among their publications on display will be THE CONSULTING ENGINEER, CONSULTING ENGINEERS' YEAR BOOK, CIVIL ENGINEER and HEATING AND AIR TREATMENT ENGINEER. Already over 500 exhibitors have booked stands at the exhibition, which will occupy over 250,000 sq.ft and there will be more than 1,000 categories of engineering products and plant on show, including the latest developments in nuclear energy plant equipment.

NUCLEAR NEWS

Uranium for Japan

SOUTH AFRICA has found a new customer for her uranium. It is Japan. Up to date only 6½ tons of uranium oxide, for use in experiments at three of Tokyo's nuclear reactors has been bought, but it is hoped that this small beginning will lead to greatly expanded business later on.

Polish Visitors

AT the invitation of Sir John Cockcroft, three scientists from the Institute of Nuclear Research, Warsaw, recently carried out a six week tour of United Kingdom nuclear research and industrial establishments. Among the firms they visited were Isotope Developments Ltd., Aldermaston, where they saw the production of nucleonic instruments and discussed at great length the potential applications of radioisotopes in industry. Their Institute has a Russian-made "swimming pool" type reactor, which will be used for irradiation of chemicals and for isotope production.

Czech Show

SIXTY-FIVE thousand sq.m of covered floor space and 60,000 sq.m of open-air sites will be made available to exhibitors at the International Trade Fair to be held from September 6th to 20th, at Brno, Czechoslovakia. Displays will consist of products of the engineering and metallurgical industries, raw materials, and semi-manufactures related to these industries, and consumer products.

Egyptian Studies

TWO senior staff members of the International Atomic Energy Agency have been surveying the isotope training facilities available in Cairo. They are Professor J. da Costa-Ribeiro, director of the division of exchange and training, and Dr. Bryan Payne, scientist in the division of isotopes. Their findings will be made available to the IAEA board of governors in case the United Arab Republic requires assistance from the Agency in extending the activities of the Cairo centre.

Sea Pollution

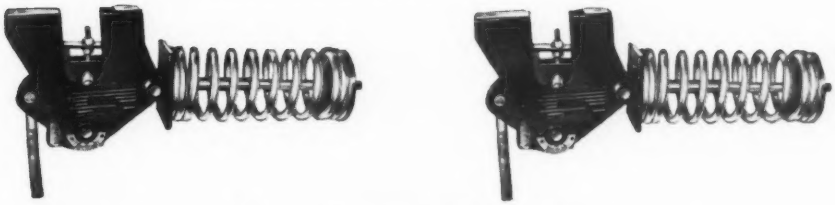
AN International Atomic Energy Agency panel of experts from 10 member countries under the chairmanship of Dr. Harry Brynielsson, director general of the Swedish Atomic Energy Co. (Aktiebolaget Atomenergi), has been meeting in Vienna to discuss the prevention of radioactive pollution of the seas by wastes from peaceful applications of nuclear energy. The countries represented were: Canada, Czechoslovakia, France, India, Japan, Netherlands, Sweden, United Kingdom, U.S.A. and U.S.S.R.

Isotope Manual

A HANDBOOK on the safe handling and use of radioisotopes has been published by the International Atomic Energy Agency, Vienna. It covers the organizational, medical and technical aspects of safety practices. Thirteen experts from ten countries have contributed to it, their work being based on studies of existing manuals and regulations in use in member countries of the agency. The manual will be periodically revised. The first edition is published in English. French, Russian and Spanish versions will follow.

Spain's Reactor

GENERAL FRANCO recently inaugurated Spain's first experimental nuclear power plant. A 3,000 kW "swimming pool" type of reactor, it was supplied by the General Electric Co., of America, under the auspices of the U.S. Atomic Energy Commission.



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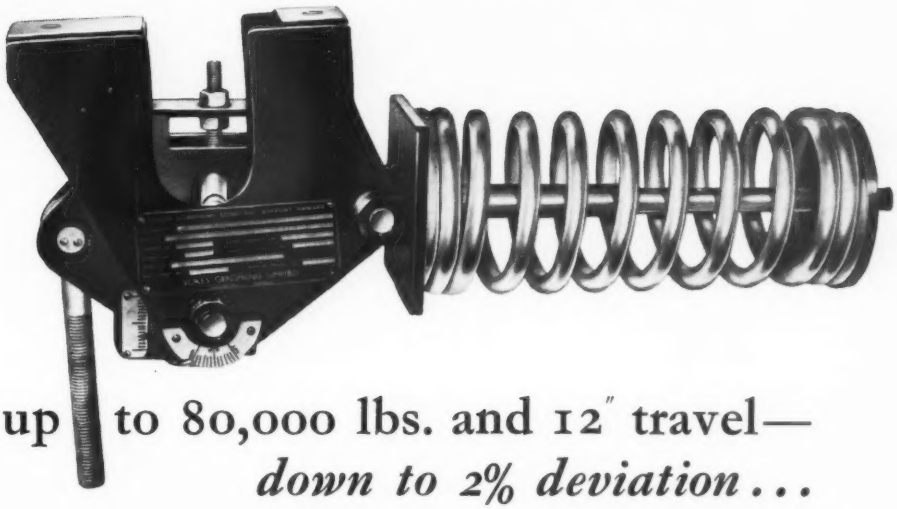

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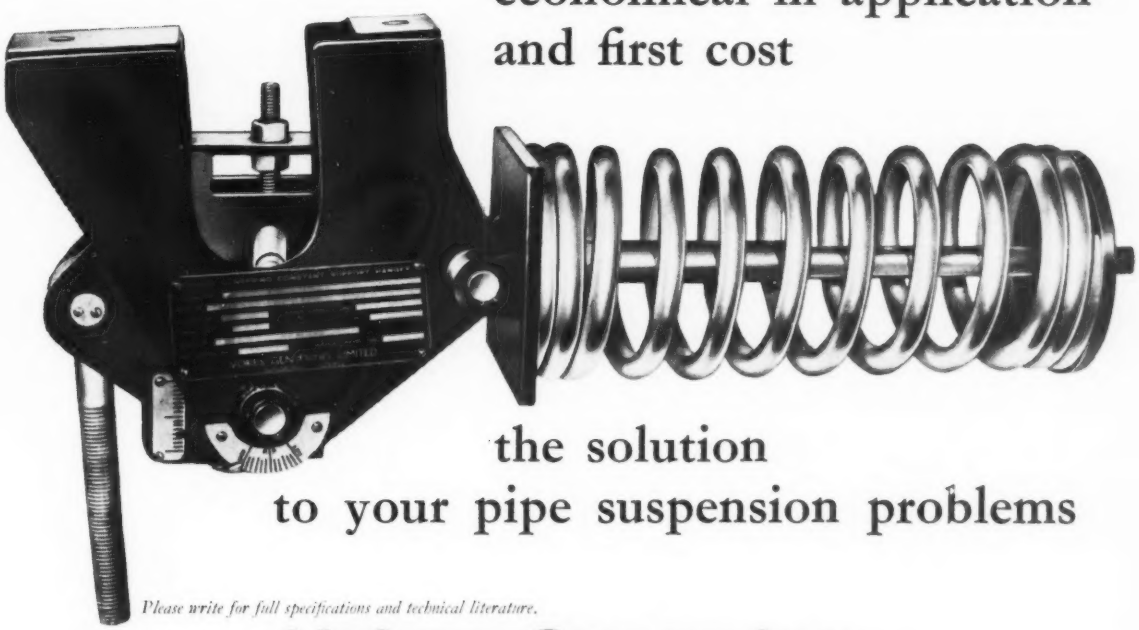

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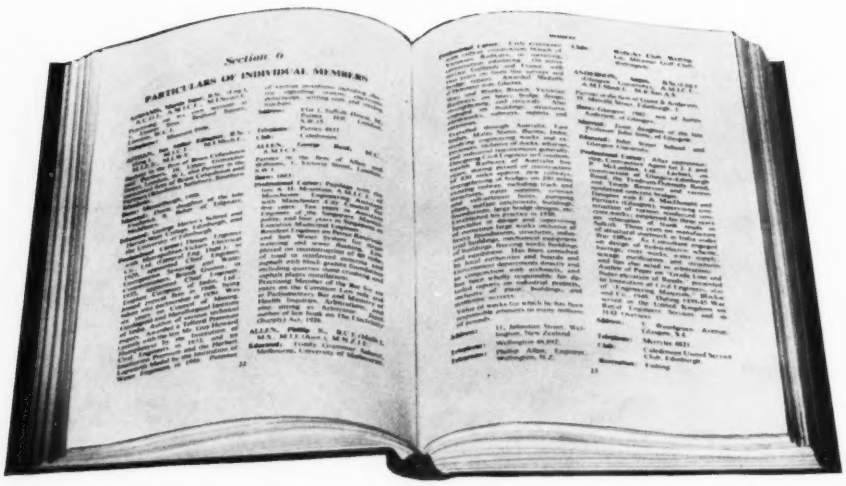

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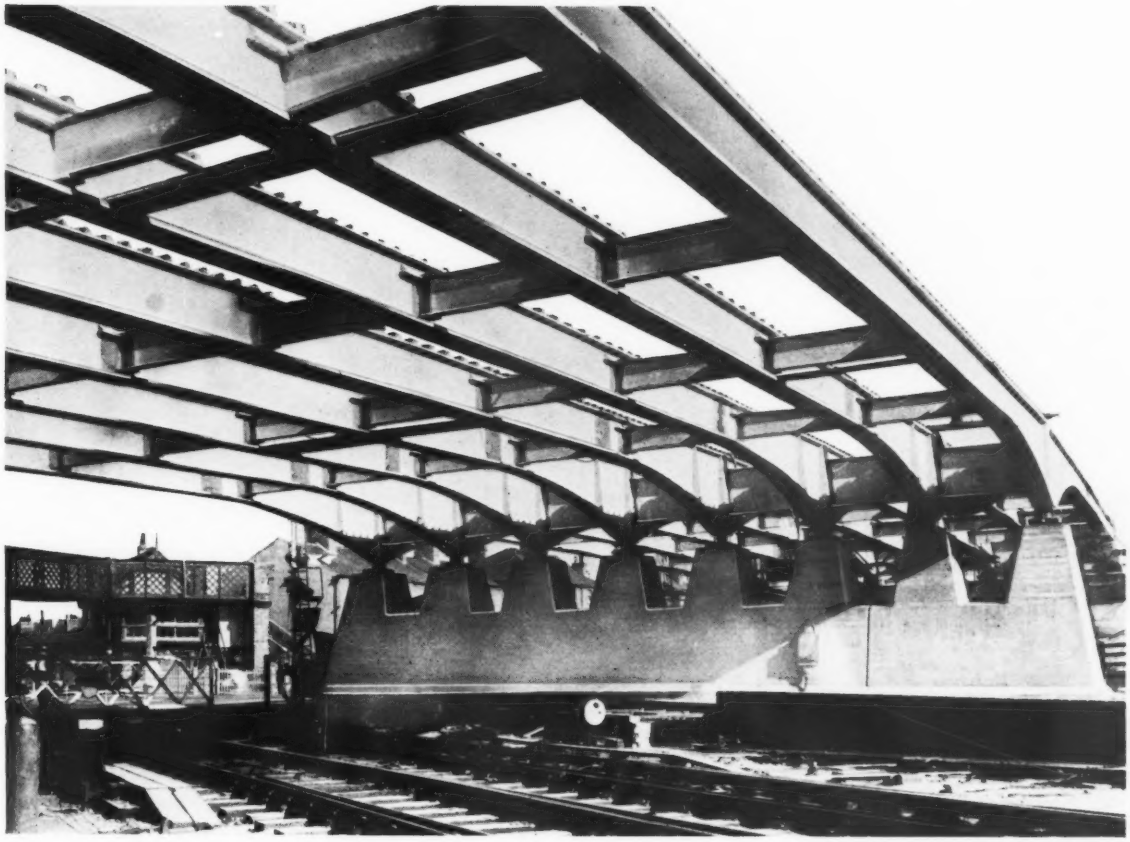

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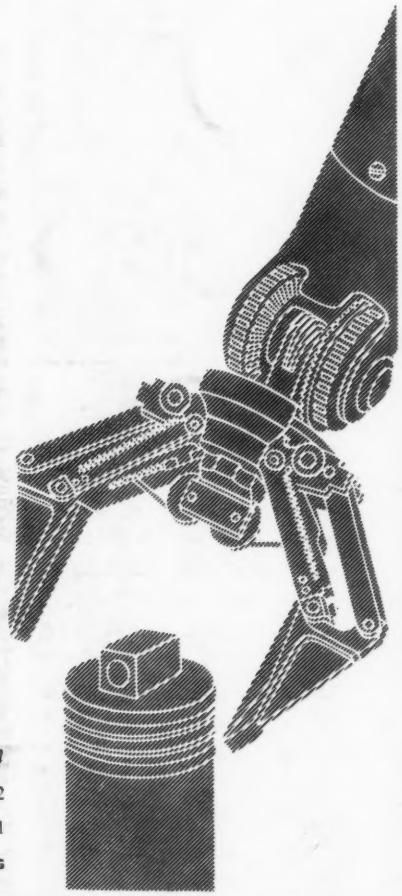

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